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Knowledge Strategy for Development: Reducing Global Inequality

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"Nathan provides an expansive view of the knowledge economy, showing how knowledge is both input and output to our well-being. He makes a compelling case that collaboration over knowledge development and use should be the policy priority rather than the current embrace of competition among tech giants and the cycles of inequality that generates. Knowledge Strategy for Development is a valuable, state-of-the-art contribution to this crucial debate."

William Milberg, Professor of Economics, The New School for Social Research, New York.

"This is an important and valuable book, drawing on a wealth of diverse historical, political-economic and cultural literatures. It analyses both the particular and the systemic drivers of knowledge and capability dynamics which have resulted in an increasingly unequal world. At the same time it offers the outlines of policy responses can produce more equitable and sustainable outcomes."

Raphie Kaplinsky, Emeritus Professor, IDS, Sussex.

ABSTRACT

The rationale for this Working Paper is to fill the gap in development strategy which ignores knowledge as an output of the economic system. A knowledge strategy for development must construct the knowledge base for the construction of knowledge and technological capabilities, from elementary through intermediate to advanced levels, which drives the structural transformation of economies from low- into middle- and even high-income economies. Knowledge is produced by individuals and groups, working in knowledge networks, with AI joining as new agents. It depends on institutions that govern access and establish the rules structuring epistemic communities. Cosmopolitanism, critical thinking, and feedback mechanisms are central to the strengthening of these knowledge ecosystems. Economic analysis emphasises competition and monopoly as the incentive for knowledge development, ignoring the role of cooperation. The Working Paper concludes by advancing a brief case for reforming international intellectual property rights regimes as a means of reducing global inequality.

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1: Why Knowledge Strategy?

A 2025 report on global inequality commissioned for the G-20, started by saying; "Inequality is one of the most urgent concerns in the world today" (Stiglitz et al, 2025:1). The report referred to data from the World Inequality Lab that the richest 10% of the people in the world account for 54% of total global income and 74% of total global wealth (op cit, 4). With Artificial Intelligence (AI), without countermeasures, global inequality is likely to increase even further (UNDP, 2025).

The G-20 report emphasised: "Inequality is a policy choice. The negative trends can be reversed" (Stiglitz et al., 2025: 3). This Element examines how knowledge strategy, both national and international, can be used to reduce global inequality and foster development in the Global South.

Angus Maddison gives a historical background to world economic history in broad contours of the movement from limited inequality to substantial inequality within the capitalist epoch: "There are much wider income gaps today than at any other time in the past. Two thousand years ago the average level for Group A [Western Europe, European offshoots of the United States, Canada, Australia and New Zealand; and Japan] and B [the rest of the world] was similar. In the year 1000 the average for Group A was lower as a result of the economic collapse after the fall of the Roman Empire. By 1820, the gap had forged ahead to a level about twice that in the rest of the world. In 1998 the gap was almost 7:1. Between the Western offshoots and Africa (the richest and the poorest) it is 19 to one," (Maddison, 2006: 29). This Element suggests studying broad contours of world equality and inequality because of the relatively open or closed flow of knowledge.

My earlier Cambridge Element (Nathan, 2024) showed a new way of looking at contemporary global history, i.e. capitalist economic history, through the lens of the importance of the creation of, command over and exclusion from advanced knowledge. Global inequality arises from the enclosure of technological knowledge and the difference between high returns to such enclosed or monopolised knowledge and the lower returns to knowledge in the commons. This is so whether it is for firms or countries. Such an analysis goes counter to mainstream theories of economic development, which assume an unimpeded flow of technological knowledge across the world.

As a follow-up to that analysis, this Element examines two major components to a knowledge strategy for reducing global inequality. The first is to formulate knowledge strategies for the Global South that enable them to build capabilities in the creation of and command over knowledge and technology. The second is to reform the global intellectual property rights system so that, while providing incentives for knowledge and technology creation, it does not lead to the creation of monopolies and thus promote inequality and even geopolitical conflict leading to war.

There are two types of analysis of the division or labour, which is also a division of knowledge and related capabilities (Fagerberg 2010). Adam Smith examines the division of labour within a factory, where this division increases productivity by developing specialised capabilities. Smith does not assume that different capabilities exist prior to the division of labour; rather, they are created by it. Ricardo, however, assumes that different capabilities exist, which result in the international division of labour through comparative advantage. If we follow Smith, we must take into account how divisions of labour and knowledge can create and change comparative advantage. With an uneven flow of knowledge, we must see how to overcome the restrictions on this flow and thus overcome disadvantageous divisions of labour, of the type in which some countries specialise in tasks that realise high profits and others in tasks that yield low profits.

In the rest of this Introduction, we will set out the approach to analysing knowledge and knowledge strategy. Our main proposition in this Introduction is that knowledge strategy is the framing of knowledge as an output of practical and theoretical activities in an economy – leading to the creation and absorption of knowledge, as well as its diffusion or exclusion from use. Knowledge strategy is formulated at macro levels, both national and international; at meso, or network, levels, including those of epistemic communities; and at micro levels, such as those of firms and gendered individuals. The knowledge output of an economy is the result of the interaction, including positive and negative feedback loops and even the lack of interaction, between the macro, meso, and micro levels of strategy and activity, and again between the national and international levels. This short description shows that knowledge strategy can be quite complex, as befitting the complexity of knowledge itself.

Knowledge and Technology as Its Embodiment

Knowledge is the ability to process information to create a theoretical or practical understanding of a subject to solve problems. Knowledge also requires the ability to mentally anticipate the necessary actions (Renn and Hyman 2012: 20).

In economic analysis, knowledge is usually taken to be what Simon Kuznets called “useful knowledge” (Kuznets 1965, 85–7) and regarded as the base of economic development. Useful knowledge would be technological knowledge or knowledge applicable to production. In the process of turning knowledge into technology, Joel Mokyr distinguishes between propositional knowledge or the ‘why’ of knowledge and instructional or prescriptive knowledge, the ‘how’ of knowledge (2002). This is similar to the distinction between theoretical and practical knowledge.

What is the status of knowledge? Knowledge is the meta-resource, or first-order resource, used to create technological capability for the use of other resources. Lundvall points out that the transformation of materials is “controlled by knowledge” (Lundvall, 1994: fn1). Knowledge is what turns things into resources, putting it at a higher level of existence than other resources.

To give an economic formulation to knowledge as a meta-resource: production is a function of the means of production, capital and labour, with a multiplicative factor that is due to knowledge. “That a technological relation between inputs and outputs is an embodiment of knowledge may seem obvious” (Arrow 2000: 16). This technological relation is the effectiveness or productivity of the productive system with capital and labour, depending on the knowledge that is embodied in their usage. A change in the knowledge base, as in the shift from manual to mechanised production, would change the effectiveness of the means of production. This demonstrates the meaning of knowledge as a meta-resource: knowledge is that which establishes the effectiveness of the means of production, an effectiveness that changes with knowledge-based innovation.

While identifying knowledge as a meta-resource, it is also necessary to go beyond the notion that knowledge is only technical or that which is directly usable in economic production. Spiritual and religious knowledge also count as knowledge in many situations. Part of what we identify as spiritual knowledge, such as the chants and various rituals of indigenous peoples, also serves as a means of memorising and transmitting practical knowledge in oral, small-scale societies, as seen in much anthropological literature (Kelly, 2015).

Therefore, it is necessary to adopt a broader definition of knowledge—including not only technological knowledge but also ritual, spiritual, and religious knowledge, as well as psychological and sexual knowledge. In this Element, however, we deal with knowledge in production.

Knowledge as an economic resource has two important characteristics. The first is that its use or consumption is non-rivalrous (Romer 1990), or non-subtractable (Hess and Ostrom 2007). This means it is a public good, in that one person's consumption of knowledge does not reduce the amount available to others. The feature of being non-subtractable extends to the world economy, particularly with the spread of the Internet, which reduces the marginal cost of transmitting knowledge to almost zero.

The second characteristic of knowledge is that its use is excludable. Thus, it is not a pure public good. Forms of exclusion have existed in history. Women have been excluded from ritual knowledge even in early indigenous societies. In caste-based India, women and lower castes were excluded from literacy, as also women and other-than Mandarins in Confucian China. In capitalism, the main form of exclusion is that of intellectual property laws, beginning in early modern Europe and now globally embodied in the WTO's TRIPS (Trade-related Aspects of Intellectual Property Rights). When we look at the history of attempts, from the early capitalist economies of the Atlantic region to the present, to restrict the use of advanced technological knowledge by countries of the Global South, it is not strange that standard economic theory ignores knowledge creation as an output of the economy.

Knowledge in Economic Theory: Neglected as Output

Solow's analysis of US growth showed that technological change contributed virtually 75 per cent of economic growth (1957). Technological change results from applying knowledge to problems in economic production, making knowledge, as an input, the driver of economic growth. The Romer model of growth (1990) goes a step further: the growth of knowledge is made endogenous, based on R&D expenditure. In this analysis, knowledge becomes an output of the economy (Arrow, 1994).

As an output of the economy, knowledge depends on the resources devoted to its production. Depending on resources allotted to it means that knowledge becomes a matter of strategy and the resulting policies. It is strategy, not just of the government but also of firms, individuals or groups, that determines resources allocated to its development. That the development of knowledge is a matter of strategy or deciding what to do in order to achieve a goal, resulting in policy of how to do it - this is the basic justification for this monograph on knowledge strategy.

Despite the Romer model treating knowledge as an output of the economy, there isa lingering hangover in development analysis centering capital accumulation. There is much discussion of the role of knowledge and skills, but not of knowledge strategy in development. For instance, Justin Yifu Lin points to the importance of "human capital through the diffusion of new knowledge or on-the-job learning, often stimulated by trade, and the college wage premium" (2012: 29). This is the human capital approach, which restricts itself to education policy and ignores both the absorption of knowledge and the creation of new knowledge. Further, it ignores the special character of knowledge as a public good, unlike human capital, which is a private good. Overall, knowledge strategy has not become a necessary part of development strategy, leaving knowledge development ad hoc and unguided by comprehensive analysis.

It was only a few heterodox economists, e.g. Alice Amsden (2001), who stressed the role of knowledge in development and the importance of the move from simple to complex knowledge. Sanjay Lall identified the movement from elementary to intermediate to advanced technological knowledge (1992) as part of, if not central to, development. What these heterodox analyses reveal is the need for a knowledge strategy to promote the structural transformation of the economy, irrespective of the development analysis we adopt. There are some pointers to knowledge strategy in development analysis, such as development through value chains in Raphael Kaplinsky and Mike Morris (2001), Dev Nathan (2018, 2023, and 2024), and Dev Nathan and Rahul S. (2024). But there is not a systematic treatment of this topic, wherein “knowledge is seen as the most important resource and learning as the most important process” (Lundvall 2016: 392) for development.

Structural transformation is key to economic transformation and can be described as the shift from an economy primarily composed of primary-sector activities to one composed of secondary- and tertiary-sector activities. In the contemporary global economy, where the production of goods and services has been splintered across economies, with those in the Global South largely engaged in deploying basic technological capabilities, development requires moving from elementary to intermediate and, then, advanced technological capabilities (Lall 1992, 1996). This movement through levels of technological capability requires knowledge strategy to operate at macro, meso and micro levels. As will be discussed in more detail throughout this Element, it is not just that development levels - of low-income countries (LICs), middle-income countries (MICs) and high-income countries (HICs) - are associated with increasing levels of technological development, but that the absorption and creation of knowledge drive the movement of structural transformation and development through these income levels.

To sum up. knowledge is an output of the economy. In addition, it is a complex product (Arrow, 1994) and thus may require a strategy with a complex strategy and policy. This is the research-and-strategy gap that this Element will attempt to fill.

Approaches to the Knowledge Economy

There is a knowledge economy in every society, which comprises “the ensemble of its social institutions and processes producing and reproducing the knowledge at its disposal, and, in particular, the knowledge on which its reproduction as a society depends,” (Renn, 2020: 7). The areas of knowledge creation extend beyond the usually analysed science establishments, academia and firms, to include sites of artisanal and artistic practices (Renn, 2019: 13) and even what would be regarded as sites of consumption and not production of knowledge, the household. It also includes sites of religious or spiritual practice that produce knowledge that might well be considered critical to the well-being, or even the reproduction, of a society. Over here, however, we are primarily concerned with what might be considered the knowledge economy in production.

Another approach to knowledge is the National Innovation System (NIS), associated with Freeman (1995) and others. As Freeman points out, the idea for the NIS was inspired by the German economist, Frederich List, famous for the infant industry theory of protection. List had pointed out in a critique of Adam Smith, "[he]… has forgotten that he himself includes (in his definition of capital) the intellectual and bodily attributes of the producers under this term. He wrongly maintains that the revenues of the nation are dependent only on the sum of its material capital…" (quoted in Freeman, 2202: 191). So, the critique of the exclusion of knowledge and learning from the economy's output is quite old, dating back at least to the 19th century.

Building on this idea of the intellectual attributes of producers, the NIS emphasises that both learning and innovation are best understood as the outcome of interaction (Lundvall, 2004: 10). The NIS then is "… the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1995: 5).

A limitation of the NIS approach, however, is that it focuses on the import and diffusion of knowledge and technology rather than on their creation. Despite concerns about developing economies, or maybe because of them, there is a concentration on absorption and diffusion without a consideration of knowledge creation. It is almost as though the creation of knowledge and technology is to be left to the developed economies. For LICs, one would agree on an initial stress on the diffusion and absorption of knowledge. But as LICs seek to move into MIC status, the role of knowledge creation, even incremental knowledge creation, must be added to those of diffusion and absorption.

This limitation of the NIS is reflected in a difference between two modes of technology innovation in the NIS. One mode emphasises promoting R&D and creating access to codified knowledge, which is known as the STI (science, technology, innovation) mode of innovation. The other mode is based largely on learning by doing, using and interacting (Lundvall 2004: 2). As Lundvall points out, the former is more stressed in American analysis, which was concerned with the creation of new technologies. New, novel technologies usually involve the application of some different principle of nature (Arthur 2009); and thus require a strong scientific and research establishment. On the other hand, technological development in firms, through learning by doing and incremental changes in knowledge result in incremental innovations, though not in the creation of new products and may not require a strong scientific and research establishment

Another approach to the knowledge economy, somewhat similar to that of the NIS, is that of Joseph Stiglitz and Bruce Greenwald (2014) on creating a learning society. Their emphasis too is on learning, which is a matter of catch-up. They do not address the issue of knowledge creation. What is stressed in this Element, however, is the necessity of combining knowledge creation, whether incremental or novel, to even advance from low-income to middle-income, and certainly from middle-income to high-income. Knowledge strategy is about more than learning; it is also about the creation of knowledge.

In analysing the nature of knowledge strategy, we need to consider the complex nature of the concept of knowledge. One can distinguish between propositional and prescriptive knowledge; between know what, know why and know how; between explicit and implicit knowledge; and between incremental and novel knowledge involving some different principle of nature. These are all parts or aspects of the complex concept of knowledge. This complexity of the concept means that knowledge strategy and resulting policy too becomes complex (Arrow 1994). And the analysis of the knowledge economy must go beyond economic factors, such as incentives for knowledge creation, to consider sociological factors, such as the formation of, connections between and rules of, epistemic communities. It will also have to consider political economy analysis (e.g., Taylor 2016) of the nature and relations among different types of competition and cooperation that could stimulate or retard the development of knowledge.

Epistemology and Ontology

Arrow (1994) refers to the social character of knowledge production, opposing methodological individualism in this respect. As the poet John Donne put it, “No man is an island, entire unto itself…” Donne wrote this about the emotional connection between individuals, but we could extend this notion to the creation of knowledge. A similar interrelation is stated in the African philosophy of *Ubuntu*, summarised as, “I am, because you are.” The animist epistemology of many indigenous peoples is also a relational epistemology, not only linking humans but also humans and other-than-human persons (Naveh and Bird-David 2013). We should contrast this with the individualism of Descartes’ “I think, therefore, I am.”

Certainly, ideas occur to individuals. However, these individuals, in their thinking, are connected to others with whom they may discuss and develop their thoughts, or they work directly in groups. Thus, any theory of knowledge, its creation and diffusion, must start with the social character of knowledge production. Within this, however, there are two approaches. One, the standard socio-economic explanation, is to relate knowledge production only to the nature of the society concerned, its institutions and even culture. This has been the way to explain differences in knowledge production as between countries of the Global North and the Global South in different phases of global capitalist history. This Eurocentric explanation based on the country's internal characteristics has ranged from institutional differences, as in the analysis of institutionalists such as Daron Acemoglu and James Robinson (2024), to economic differences, as in Marx's analysis of capitalism's drive to constantly revolutionise the means of production or technology.

In contrast, the historical analysis of the Scientific and Industrial Revolutions in Western Europe highlights the contributions of Asian science and technology to Western success. The trading Silk Road was also the route through which knowledge, ideas and gadgets, such as printing, explosives and the compass, moved from China to the West (Hobson 2004); similarly, the recently christened Golden Road was the route through which the concepts of zero, the decimal system and what became known as the Fibonacci sequence of numbers were transmitted from India to the West (Dalrymple 2024). These examples are sufficient to demonstrate that the knowledge of the Scientific Revolution in the West had substantial Eastern origins (Goody 2006). This shows the need to look not only at the institutional attributes of knowledge centres in the West, but also at their network connections with knowledge centres elsewhere in the world.

We can take an example from the history of art to illustrate how ideas are transmitted, sometimes appropriated, from one geography to another. Picasso broke away from the European tradition of representing objects from a single perspective, learning from West African sculptures the use of multiple perspectives to produce something that seems distorted yet conveys emotion, rejecting the European naturalist representation of the body (Arnason and Prather, 1998). Thus, Western cubism owes much to West African art, showing the importance of knowledge networks, including those of art and, of course, science and technology.

In addition to individualism, the Cartesian approach to knowledge posits a mind-matter dichotomy, in which knowledge is the creation of the human mind, while all else is matter or nature. Is there evidence to show that the difference between the human and non-human is one of degree, not of category as in the mind-matter dichotomy? For instance, it was long held that tool-making distinguished humans from other animals, including apes. But Jane Goodall's discovery that apes, too, made tools forced a rethinking of that imputed category difference.

Language, too, is held to be a feature of culture rather than nature. But animals and birds clearly have forms of communication, which constitute language. What they have not developed is written communication, as humans have. But Peter Wohlleben's work (2015) showed that trees communicate with one another and even form alliances. David Premack and Guy Woodruff (1976) showed empirically that chimpanzees impute mental states to themselves and others, specifically humans in their experiment.

These different ontological understandings of the nature of beings have an impact on one's approach to epistemology. The naturalist ontology of a strict difference between humans and the rest of nature, results in the Cartesian epistemology where the subject and object of study are separated as category differences. In an alternative animist (or posthumanist) ontology, "Instead of framing one's target of study as a separate subject, here it is framed as a subject co-living with the learner" (Naveh and Bird-David 2013, 29).

The historian Fernand Braudel pointed out that every knowledge system “draws its essential insights from the ‘view of the world’ it adopts” (Braudel, 1993, 16). The belief that human beings are culture and non-humans are nature would then result in a subject-object dichotomy in the production of knowledge. We, humans, are the universal subjects, while all else are objects. This dichotomy could also extend to the expert, who alone is the subject and even other human beings are objects; a very non-democratic epistemology. In contrast, if we adopt an animist or posthuman ontology in which there is no sharp categorical distinction between humans and non-humans, then we are more likely to adopt a relational, more democratic epistemology that acknowledges the contributions of various beings and species to the production of knowledge.

There is also yet another ontology that is common to both Confucian and the Hindu caste approaches – and, I would add, racism. It is “predicated on the idea that all the entities in the world are fragmented into a multiplicity of essences, forms and substances separated by minute intervals, often ordered along a graded scale… “ (Descola, 2013, 27). As a result, not only non-human beings but even humans have different essences, hierarchically organised as in the caste system and racism.

Further, in the Cartesian system, translated into economic terms, the impact on nature is an externality. The neo-classical definition of economics, due to Lionel Robbins, as the study of the allocation of resources between competing ends, means that there is no consideration in economics of the effect of using natural resources on the resources themselves, since that effect is not an economic matter. Thus, this externality is something that we need not worry about and, therefore, not analyse.

This is the outlook of the individual capitalist extended to the macro-economic, even planetary scale. But we are coming to realise that there is an interdependence between humans and other parts of nature, something that economic reductionism ignores – we have brought about global warming and related climate change. As we try to deal with the damages brought about by the Cartesian epistemology (and ontology) we surely cannot do that without a change in our way of thinking, incorporating relational analysis drawn from animist or posthumanist epistemology. Species relate to each other. Thus, relational analysis promotes scientific investigation grounded in interspecies dependence and can lead to a “multi-species democracy” (Rana Dasgupta, 2026).

In terms of knowledge development, relational epistemology emphasises the relations between humans and other beings. For instance, the indigenous peoples of the Amazon understood that the bark of cinchona trees had a beneficial effect in treating malaria. This relational understanding of cinchona, however, did not extend to understanding the nature of the compound quinine in the cinchona bark, which had this beneficial effect. That investigation was left to the reductionist epistemology of Cartesian science, which deconstructs complex substances into their elements and examines the nature of those elements.

Ceteris paribus, or all else remaining constant or the same, is a foundational assumption in economics and much of science. This has enabled the enormous development of science and technology that makes up the contemporary world. However, we now know that such reductionism ignores the inter-relations between beings, between humans and non-humans, and has even brought about the current environmental crisis by ignoring the external effects of fossil-fuel-based industrial and agricultural development. On the other hand, an epistemology that is only relational has its limitations in its disregard for the internal nature of things. One may say what is needed is to combine both types of analysis – of inter-relations and internal structures and not just one or the other. We will return to this issue in the concluding section.

Outline of the Element

Having introduced the nature and scope of knowledge strategy, we then outline the main features of the knowledge economy in capitalism. This is followed by an examination of how the knowledge problem is modified by the current organisation of production in global value chains (GVCs) between the Global North and the Global South. This sets out the *what* of knowledge strategy, followed by an analysis of the *how* of or policy for knowledge production. Using meso-level network analysis, this section goes beyond the usual incentive-based economic analysis to incorporate historical and sociological factors in the development of the knowledge economy. It deals with factors that could promote or impede the development of knowledge systems. Given that technological competition is a pervasive feature of the global capitalist system, we then examine how this knowledge competition plays out in the contemporary world economy, focusing on competition in frontier knowledge and technologies in the contemporary world economy between the USA and China. The power law distribution of knowledge creation has also led to a bipolar world. The last Section first synthesizes the analyses of this Element and then addresses possible reform measures to support the spread of knowledge as a way to reduce global inequality while providing incentives for the creation of knowledge.

2: The Knowledge Economy in Capitalism

In this Section, we examine the nature of the knowledge economy within capitalism. The main propositions guiding this Section are: (1) the capitalist economy potentially continuously revolutionises the knowledge economy; and (2) AI is a new actor in the knowledge economy, both augmenting and replacing human capabilities.

From learning by doing to learning by study

In traditional societies, knowledge was acquired basically through children working with their parents, usually girls with mothers and boys with fathers, or as apprentices in craft guilds. The method of learning was one of seeing and doing. Very few forms of knowledge, such as ritual or warfare, required literacy or the ability to read sacred texts, which were often in languages, e.g. Latin or Sanskrit, that were not the vernacular.

Consequently, with learning basically by seeing and doing and with children working with their parents or other elders, child labour, as we call it now, was not a problem. Child labour was a form of generational knowledge transmission. But with the capitalist economy, there is a shift in the manner of transmitting knowledge – from learning by doing to learning by study (Renn, 2020).

Literacy for Knowledge Transmission

A major change in this transmission of knowledge was made possible by the invention of printing in China. But with the knowledge economy still based on a literate few and an illiterate majority, there was little demand for its use to print large numbers of copies of important books. The change came about with the Christian Reformation in early modern Europe. With the doctrine that people did not need intermediaries, such as priests or the Pope, for communion with God, there was a need and a market for large-scale availability of copies of the Bible. This is why the Chinese invention of printing was adopted to make the Bible widely available in Europe, but not in China itself, India, or the Ottoman Empire.

Education results in both literacy and numeracy and, now also, digital literacy. This makes it imperative for children in contemporary capitalism to spend many years in school and other forms of formal education. Some craft knowledge and agricultural knowledge may still be passed on from parents to children, but that is no longer the dominant form of knowledge transmission. In fact, with the growing digitisation of economies and the expansion of global markets, even craftworkers need to know how to use new technologies, including smartphones, thereby increasing the importance of education as a means of acquiring general knowledge.

Another factor in the importance of some years of schooling in creating an industrial working class was brought out by the manager of a garment factory in Bangladesh, who said that it was through school that workers learned the discipline of staying in one place; a discipline, he pointed out, uneducated agricultural workers do not have. School education then is a necessary component of Michel Foucault's *Discipline and Punish* routine of capitalism.

Countries of East and South-east Asia quickly realised the importance of universal education, with Japan, as would be expected, the forerunner in the 19^{th} century itself. In South Asia, however, only Sri Lanka adopted universal education as a goal even before independence. India, on the other hand, was a laggard, making education compulsory only in 2010. India's weakness in universalising education can be taken as a reflection of the long shadow of Hindu values with their prohibition of knowledge of the sacred texts for the lower castes and women.

Besides basic education, there is, of course, a need for higher technical and scientific education. Sometimes this may lead to a higher supply of such technical and scientific personnel than the demand for them. Demand depends on the extent to which the economy undertakes research, approximated by the levels of R&D expenditure by both the state and private organisations and firms. Weak demand for such knowledge workers is often a feature of economies of the Global South (Arocena and Sutz, 2010). The best example of this is India, which annually produces far more science and IT graduates than there is domestic demand for them. This leads to many graduates being exported as a form of service export. In addition, many Fortune 2,000 companies have also set up research centres in India to utilise this supply of relatively cheap scientific personnel. This Indian model of providing basic scientific and technical personnel for the Global North is now under threat, with AI likely to take over many low- and middle-level, routine and even non-routine tasks in software and technology deployment.

Education and Its Impact on the Structure of the Economy

In addition to neglecting primary education, post-independence educational policy in India continued the British colonial pattern of emphasising tertiary education. The British needed clerks to run the administrative machinery of the state, engineers to work on the railways and other modern infrastructure, and personnel to serve in the British Indian Army. China, on the other hand, after liberation in 1949, began with universal primary education and built its higher education system. The differences in educational policy – with India placing more emphasis on tertiary education and China on universal primary education may well have had an important role to play in China becoming the "factory of the world" while India became the "back office of the world" in the 21^{st} Century. This shows that educational policy could even affect the economic structure.

Firms as Learning Organizations

Firms may be considered as a set of resources of different kinds, such as plant and equipment embodying a particular technology, along with management and labour. The key part, as Edith Penrose's *Theory of the Firm* (1995) emphasised, is the collective knowledge of the firm, so that 'a firm's rate of growth is limited by the growth of knowledge within it' (Penrose, 1995: xvi, also quoted in Turvani, 2007: 227).

Growth of firms, or of the economy for that matter, then is not a mere accumulation of capital and employment of labour, but also and critically so the growth of knowledge. The firm's knowledge directly affects the efficacy of technology use, as technology alone does not determine productivity. There is an essential learning process in the use of technology, what Arrow (1962) called learning by doing, which he identified as leading to increasing returns in industry. The reason for learning by doing is that there is much tacit knowledge in the use or operation of any technology, and this tacit knowledge is acquired by doing, in the manner that one can learn to ride a bicycle only by doing it.

Firm-level learning, however, is not just an output of production, as discussed above. It is also the result of intentional policies of learning, which include training, market and product research and R&D, even if the latter is sometimes not formally designated as R&D. These types of learning are called "learning by searching" (Lundvall and Johnson, 1994: 32). Why does this have to be a continuous process rather than just an initial event on setting up a firm? Competition in capitalism drives technological change that continually destroys older competencies and requires learning newer ones. Even in what seems to be just the same sewing machine, changes every now and then with new functions and speeds are inserted into the machine. Each time a new version of a machine is introduced, some amount of learning is necessarily involved. Lundvall and Johnson point out, "The most important consequence of the advent of industrialisation is that it made learning a much more fundamental and strategic process than before" (1994: 24).[1]

Keeping up with competition in an international market will, thus, necessarily require investment in firm-level learning. Even in competitive domestic markets, firm-level learning that leads to innovation is part of the attempt to gain a competitive advantage. These innovations may involve just incremental changes and may well be "not new in the world", but they embody learning, meaning knowledge acquisition by the firms. As emphasised in both Lundvall and Johnson (1994) and Stiglitz and Greenwald (2014), firms have to be learning organisations.

[1] This sub-section owes much to Lundvall and Johnson (1994).

Knowledge and Workforce Development

Given that workers are a crucial resource for the firm and important to its productivity, means that a firm must have a policy for workforce development. Autor (2013) and Acemoglu and Autor (2010) divide tasks into three types—(i) high-skill, analytic and problem-solving tasks; (ii) middle-skill, routine or codifiable manual and office tasks; and (iii) low-skill, in-person service tasks. To perform these tasks, workers need the required capabilities, defined as the competences that enable a worker to perform a task or utilise a technology in production (modifying Nubler 2013: 122).

Capabilities are based on or reside in the knowledge set/s possessed by an individual. This knowledge is of two types—conceptual, which is "knowing that", and procedural, which is "knowing how to" (Nubler 2013). "Knowing how to" is the knowledge required to operate a machine or perform an operation. But in order to be able to spot and remedy defects, workers need the ability to not just operate a machine but also to correct it, which requires the conceptual knowledge of "knowing that," in order, for instance, to undertake the analytical task of correcting or setting numerically controlled machine tools or other automatic machines. Thus, firms need to go beyond simple learning-by-doing and invest in building workers' knowledge-based capabilities.

The building of capabilities depends on the employment or labour practices, which can be classified on the basis of employees' work systems as follows: the standard operator or Taylorist system, with no decision-making functions for workers; the involvement of large numbers of employees in Quality Circles, with some decision-making functions, as in the Toyota system; and the semi-autonomous Work Team, which decides on its own routines as in IT companies.

In the Quality Circle and the Work Team, workers need to be given the authority to take some shopfloor decisions, such as in stopping assembly lines when they detect flaws. Studies show that allowing more shop-floor decision-making in the workforce improves firm performance (Appelbaum et al. 2000; Ichinowski and Shaw 2003; Ton 2014). But empirical studies of labour practices in India show that such decision-making authority is rarely granted to workers in India (Nathan, Saripalle and Gurunathan, 2016; Nathan and Kumar, 2016). In China too, the cases of workers' suicides, as in the factories supplying Apple products (Chan, Pun and Selden, 2016 and 2021), reflect the strains of Taylorist methods of workforce organisation. As the knowledge content of tasks increases, one would expect workforce systems to give workers more shopfloor decision-making power. But there is, in Harry Braverman's analysis, the countertrend of de-skilling as in digital-Taylorism (see Noronha and D-Cruz, 2016).

Overall, a weakness of many labour practices is that they do not give due place to employees or workers as actors in the knowledge economy. They, however, are just one of many people who are not considered actors in the knowledge economy.

Women and Other Invisible Actors in the Knowledge Economy

Women, in their roles as the primary homemakers, are also not considered part of the knowledge economy. Nor consumers, who, in economic analysis, are just the passive users of products made by firms. If the ability to mentally anticipate or perform the required actions (Renn, 2020: 426), is taken as a characteristic of knowledge, then clearly women deploy knowledge in the performance of home-making tasks.

Similarly, denying the status of knowledge workers to forest-dwellers ignores the knowledge they have acquired and developed through their gathering activities. “They [hunter-gatherers] selectively harvested and groomed plants with desirable features like large seed heads and weeded out those with small, stunted fruits. They also removed unwanted species and diseased individuals from the community of their favored plants” (Bertness, 2020: 59). But much of this labour of forest management, however, is invisible to the external observer (Padoch, 1996: 36). Being invisible to external observers, forest-dwellers’ activities in managing forests are ignored and forests are regarded as just the products of unaltered nature.

If certain outputs, such as home-making or forests, are not counted as resulting from the use of knowledge, then other products are attributed to organisations such as firms, thereby erasing the role of employees or workers who create the knowledge within those firms. There is knowledge in the workplace, and employees generate intellectual advances; but the now-established laws of corporations accord rights over this knowledge and creations to the firms by which they are employed. The workers involved in these knowledge creations are rendered invisible, and their creative work is alienated by the firm (Fisk, 2009). Just as Marx pointed out that the manual labour of the worker is alienated by the capitalist firm, the worker’s intellectual labour, or their creations of knowledge, are also alienated by the capitalist firm.

Yet another category of actors in the knowledge economy who have been invisible is consumers. It was only with Wiebe Bijker’s *Of Bicycles, Bakelite and Bulbs* (1997), and Eric von Hippel’s *Democratizing Innovation* (2005) that the role of consumers or users was recognised in the development of products ranging from mountain bikes to surgical instruments, surfboards, and software. But if we look back at the history of technology, we might well find that many objects came to their present shape through incorporating the knowledge inputs of various users, including women in households.

Along with the denial of activities as embodiments of knowledge, there are also forms of alienation or appropriation of knowledge, such as the appropriation of indigenous medical knowledge by pharmaceutical companies. But the important point here is that there are actors in the knowledge economy, such as women, workers or employees, and forest-dwellers whose knowledge-based actions are made invisible and their intellectual products appropriated by patriarchal families, corporations or the state. The invisibilization of actors can also be carried out by declaring that some knowledge is non-knowledge, that it is something that just exists in nature. In early modern France, though women such as midwives practiced medicine, their work was not considered medicine. The Faculty of Medicine in Paris declared that "what women did in assisting each other in birth was not considered medicine" (Green, 2008: 323), which must mean that what midwives did was just a natural act; in the dualist Cartesian ontology, just a matter of nature rather than culture.

The exclusion of women and forest-dwellers as users and creators of knowledge in their respective domains means that knowledge systems would overlook their potential contributions to knowledge development in those domains. Negating feedback loops between knowledge gained from practice and theory would weaken the knowledge economy.

Centres of Advanced Learning and Research

Capitalist economies typically have large centres of advanced learning and research, the universities and related research institutes, whether in the private or public sectors. These centres also include firms, particularly large monopolies, which are often regarded as the creators of new technologies. Of course, centres of advancing learning and research pre-date capitalism; but capitalism drives the continual production of new knowledge since, as Marx famously argued, competition among capital provides the impetus for the revolutionising of the means of production. This, however, was not carried out by private firms alone. As Marina Mazuccatto (2013) persuasively argued, public research is critical to the formation of new technologies, which are then commercialised by the private sector. The Internet and GPS are among the advances made by public-sector entities. Even when private firms commercialise these technological advances, they are often supported by basic research with public money, as was the case with the COVID-19 vaccines based on MRNA technologies developed by the public sector National Institutes of Health (NIH) in the USA.

A feature of institutions of advanced learning in a capitalist economy, viz. its universities, is that they are usually large, multi-disciplinary centres. This contrasts with the smaller craft-based or teacher-centric organisations in earlier societies. There were earlier large interdisciplinary centres of learning, such as the Buddhist centre Nalanda in India. But they were the exception, rather than the norm, which remained that of the smaller teacher- (or guru) centric organisations of the transmission of knowledge in pre-capitalist knowledge economies. The French traveller, Francois Bernier, who in the 17th Century visited Benares, India's centre of Hindu learning, compared the small number of disciples of the gurus, in contrast to the large number of students in universities of Western Europe (quoted in Raychaudhuri, 2008). There is a role for close interaction between teacher and student in learning. Large inter-disciplinary universities, however, provide advantages of scale and scope, and inter-disciplinarity in the development and absorption of knowledge.

In monopoly capitalism, research units of large corporations have become important in creating and translating knowledge into production. The pharmaceutical majors' role in drug development, Bell Labs' role in telecommunications innovations, and Xerox's role in creating touch screens are well-known. Often, however, these advances have been built on basic research funded by state units and open-source knowledge. In current AI research, the proprietary models of OpenAI and Anthropic, etc., have been built on many open–source advances and public data (SHAI, 2026). The corporate research labs play a major role in translating propositional knowledge, largely created in universities, into prescriptive knowledge, i.e. the movement from why to how, which is critical in moving from knowledge to technology. But these corporate labs are not the only players in this process. Public-sector projects also facilitate the commercialisation of basic knowledge into economically viable technology (Mazzucato 2006).

AI and the Knowledge Economy

The advent of Artificial Intelligence (AI), in the form of machines that learn, has already made a difference in the knowledge economy. Before AI, machines could take over manual work; with IT, computerised algorithms could also take over routine cognitive work (Autor, Acemoglu and Johnson, 2026), as seen in the algorithms that are part of the production of both goods and services. The first example of a machine that undertakes routine cognitive work in production is the Jacquard weaving loom, created in 1804, in which weaving instructions, or weaving software, were embedded in punched cards, much as punched cards were used in early computers. The Jacquard loom, however, could only follow the instructions in the punched cards. Now, with AI we have machines that can learn and correct errors, embodying Arrow's learning by doing. This allows them into the realm of non-routine cognitive work that Autor, Acemoglu and Robinson (2026) hope would remain the unique domain of humans.

The diffusion of knowledge has so far been largely through human teachers and printed, and more recently digital or screen, material. With digitisation, instructional material, such as lectures, can be digitised and, as with Netflix, videos can be streamed with virtually zero marginal cost to almost unlimited numbers of students. This has led to the spread of free or low-cost web-based distance learning programmes, known as MOOCs (massive open online courses). What remains for humans now is to carry out one-to-one tutoring, an important part of education (Ram Reddy, 2025, https://www.youtube.com/watch?v=ydnOSMbyyQo0). With AI agents, however, one-to-one learning can also be automated, i.e., performed by non-human agents. Further, once these AI agents have been created, there is virtually zero marginal cost in making this tutoring available, i.e. its consumption is non-rivalrous. This will enable the spread of high-quality education worldwide through even low-cost translation, much like how Netflix revolutionised the distribution of entertainment services.

Students are now using AI agents in preparing assignments. Some negative effects of this widespread practice have already been noted. Kosmyna et al (2025) point out that the use of ChatGPT for writing reduces users' ability to memorise and accurately record their own arguments and, more ominously, that it appears to do so by changing neural connections in users' brains. ChatGPT is also found to affect critical thinking (Gerlich 2024). Discussions with university teachers show that the outputs of students who use ChatGPT look very similar, thereby negating the role of diversity, which is important for creativity.

Acemoglu, Qong and Osdaglar (2026) point to one possibly disastrous consequence of the widespread use of AI in knowledge learning. They distinguish between two kinds of knowledge creation – general knowledge and context-specific knowledge. The former, for instance, concerns theories of financial portfolio allocation, while the latter is a specific suggestion for an individual portfolio. The benefit, or private return, to a knowledge actor primarily comes from context-specific knowledge. The addition to general knowledge, however, is an unintended consequence of context-specific knowledge, as the latter can modify the former. If, however, everyone were to use AI agents to provide context-specific knowledge, then all context-specific knowledge would be similar, and there would then be no further addition to general knowledge. This, they argue, could lead to the collapse of the advance of general knowledge, on which AI agents depend for their learning. Dani Rodrik commented that 'For artificial intelligence to work for us, it should not think for us' (2026).

Uniformity and the absence of critical thinking could be brought about even without AI, and many governments around the world are trying to achieve these negative qualities in support of religious and non-religious authoritarianism. But these findings suggest that AI can have significant consequences beyond the spread of knowledge, and that it could be used to attack critical thinking, just as it could be used to strengthen surveillance capitalism (Zuboff, 2019), which has become a feature of both economic and political systems. Knowledge policy will have to find ways to address or set guardrails against such negative effects to enable sustained benefit from AI.

AI and Scientific Research

AI, with its vast capacity for data analysis and management, limited only by the extent of computational power (or compute) that a corporation or country can command, can make a big difference in knowledge management, including research. AI has created massive data-analysis capacity. AI agents can connect disparate domains of knowledge and easily fill structural gaps in unconnected research domains. It can also fill the gap between research and its utilisation in different circuits of knowledge, such as between research centres and production units. Overall, knowledge management will be much more efficiently managed and provide economies of scope by connecting different domains of knowledge and practice. A survey by Roberto Cerchione, Giuseppe Liccardo and Renato Passaro (2026) provides an empirical examination of how AI has improved the efficiency of knowledge management.

Cataloguing what all can be done with AI and trying to suggest what AI cannot do – such a list can quickly get out of date as newer areas are taken up by AI. Instead, we take a summary from Fudan University and the Shanghai Academy of AI for Science (2025) and from the Stanford Human-Centered AI Institute (SHAI, 2026). AI can undertake both deductive and inductive research. It eliminates the need for prior hypotheses, deriving them inductively from the available data. It can work with large-scale datasets (big data), enhancing human capabilities in this area. Stanford reported that frontier models now "meet or exceed human capabilities on items like PhD-level science questions, multimodal reasoning and competition mathematics" (SHAI, 2026: 6), though they do poorly on telling time (!) or managing multiple-level planning.

However, as is usual in data analysis, AI can identify correlations but cannot provide causal explanations for them. It also has limitations in processing "noisy or incomplete data and discovering principles in complex systems" (Fudan and SAAS, 205: 3). Further, since AI trains on existing data, it would not be able to deal with novel systems that might be created in our still evolving universe. Will it be able to spot unknown relationships, such as the one that led to the discovery of penicillin (Aravinda, 2025)? AI is more efficient than humans in solving small issues, will then humans be left only with the knowledge tasks of dealing with big issues?

More important than identifying what AI can and cannot do at present is understanding whether AI represents a new type of analyst that both adds to and replaces human capabilities. There has been much discussion on whether AI is or can be conscious or feel emotions. It is perhaps more useful to see whether AI is an analytical agent that is intelligent and different from humans in degree, not kind. Herbert Simon, a winner of both the economics Nobel Prize and the Turing AI award, wrote in 1957, "We have invented a computer program capable of thinking non-numerically, and thereby solved the venerable mind-body problem" (quoted in Russell and Norvig, 2022: 39 and 35). The AI agent is certainly a partner to humans in the knowledge economy.

Should we add AI to the list of non-human beings that are different in degree and not kind from human beings, at least in the matter of thinking, even if not in emotions? Descola (2013) identifies two properties that constitute all beings – physicality (or body) and interiority, that is, "self-reflexive inwardness" (or mind), which can also be denoted by the term intentionality, attributed to Husserl. Does an AI agent that has the capacity to carry out reinforcement learning, Arrow's learning by doing, or untutored learning from data – does it have interiority? Or a mind?

We can recast the question in terms of simpler intentionality, putting aside complicated issues like emotions. Does AI have intentionality, i.e., can it identify a problem in achieving its human-defined goals and then think of and take action to resolve it? In 'dark factories', the AI-robotic systems, or physical AI, can undertake not just algorithmically determined production but even self-correct errors.

Of course, we want AI systems to seek to realise human-defined goals and not otherwise. The most famous example of an anti-human goal-defined intention is that of Hal, the computer in the novel-movie *Space Odyssey 2001*, who said to the last remaining human companion in the spaceship, "This mission is too important for me to allow you to jeopardise it." A warning to humanity: do not allow AI systems to set their own goals. Hopefully, we will move to ban the development of autonomous weapons, noting that the technology behind them is similar to that of self-driving cars (Russell and Norvig, 2022, 49). AI agents that can recreate themselves and even make better versions of themselves are even more dangerous and could result in the extinction of humans– such a recursive development needs to be checked through international agreements on what can and cannot be done with AI. If nuclear arms agreements were a feature of the last Cold War, agreements on guardrails for AI development could be a feature of the current technological competition between the USA and China.

Overall, however, the acceptance of AI's combined physicality and intentionality (body and mind) means that AI agents must be acknowledged as actors in the knowledge economy. This changes epistemology - we are in a new era of the collaboration of human and human-created AI in the creation of knowledge. Called posthumanism (Braidotti, 2013; and the recent review in Herbrechter, 2025), this approach emphasises that humans are tied to other non-human beings, as well as to the technologies we create.

With regard to the creation of knowledge, is AI a singular technology, that is, one that will impact the future evolution of humans, in the way that the technology of controlling fire was a singularity in that it allowed humans to go beyond that which other primates could achieve, becoming human? As the gatherer-hunter Andamanese told the British anthropologist Radcliffe-Brown in the 1920s - fire is what distinguishes humans from animals (1922). We can then talk of a pre-fire and post-fire human history. Is subsequent human history also likely to be divided into pre-AI and post-AI history?

3: Knowledge Strategy in GVC Capitalism

In this section we discuss the tasks to be dealt with by knowledge strategy. We first situate knowledge in the Global South within the contemporary fragmentation of production in global value chains (GVCs) and then identify the knowledge strategies that economies pursue as they construct their development paths.

Our main proposition in this Section is that knowledge advances result in, and not just accompany, the transformation of economies from low (LIC - low income countries), to middle (MIC – middle income countries) and then high- income (HIC – high income countries), with such a transformation located within but overcoming the global division of knowledge through global value chains (GVCs).

GVCs and the Fragmentation of Knowledge

Contemporary production is characterised by outsourcing as offshoring, i.e. the fragmentation of production among independent but hierarchically related firms located in different countries, with headquarter or lead firms largely in the Global North and supplier or production firms in the Global South. Of course, with development in the Global South, some countries, China in particular, have emerged as the source of new headquarter firms.

In GVCs, the enclosed or monopolised knowledge that leads to the creation of new products is concentrated in headquarter firms and their countries in the Global North, while producing firms carry out their tasks with knowledge that is commoditised or in the commons. This results in a hierarchy of profit rates. Monopolised knowledge allows the capture of high profits, often around 40 to 50%, for headquarter firms; while knowledge that is commoditised or in the commons gets around 10% or less for the manufacturers. In the famous case of iPhones, Apple got a gross profit margin of 43.5% in 2012, while the assembler FoxConn, got just about 5% (Raj-Reichert 2018). There is a similar inequality in the distribution of value shares – Apple captured 58.5% of total value, while the Chinese assemblers captured just 1.5% (Chan, Pun and Selden, 2016). In the case of garments too, brands from the Global North also secured margins around 50 per cent, while garment manufacturers in India got 10 per cent or less (Nathan et al, 2022).

Knowledge is both an input into and an output of production. Consequently, with the distribution of production in GPNs “the knowledge needed to create value is being increasingly dispersed, either in direct geographical terms, or in technological disciplines” (Foss, 2006, 9). The number of knowledge nodes is increasing, and firms need to tap them “not just internally but also through an increasing number of alliances and network relations…” (Foss, 2006, 1).

However, “high-wage and knowledge-intensive activities are more prone to agglomeration effects and hence resistant to geographic dispersion [as through GVCs]” (Ernst, 2000, p. 12). Knowledge-intensive activities remain concentrated in firms in the Global North. But the development of GPNs inevitably leads to the dispersion and migration of some knowledge, though mainly in low-knowledge-intensive activities. Further, whether it is in computing systems, IT services, electronics or even garments, the push of headquarter firms to reduce costs leads to an outsourcing of parts of design, though conception and architecture would be retained by the headquarter firm. Manufacture of automobile components, for instance, includes substantial design activities. Electronic component manufacture also requires “cross-functional, knowledge-intensive support services that are intrinsically linked with production” (Ernst, 2000, p. 16). This leads to the migration of some knowledge. The manufacture of chips shifted to Asia, and with it the knowledge of the tasks involved in their manufacture, including assembly, though the latter might not be difficult to acquire.

“To the degree that the flagship [the first-tier corporation] has moved to *global sourcing* … this implies an *erosion* of the *collective knowledge* which used to be a characteristic feature of the flagship’s home location. But this knowledge flow is restricted to manufacturing, restricted to a narrow range of tasks, such as quality control” (Staritz and Whitfield, 2019: 396) and does not cover design tasks (De Marchi, Di Maria and Gereffi, 2018), tasks that involve a lot of tacit knowledge.

In some cases, that collective knowledge may have migrated for good to the suppliers’ overseas cluster(s)….” (Ernst, 2000, p. 17). For instance, Texas Instruments officials said that to solve production problems at their US plants, “We have to send our Malaysian engineers to solve their problems” (quoted in Ernst, 2000, p. 17). A recent example of this knowledge export is the employment of Korean workers to set up an advanced automotive plant in the USA. This led to the deportation of some of these specialised Korean engineers under US President Trump’s anti-immigration policies. But, according to media reports, the deportation was only temporary as the required specialised Korean engineers returned with valid papers.

Nevertheless, the headquarter firms retain control of hard-core R&D in creating new products and strategic marketing. Some of the R&D efforts of headquarter firms may themselves be carried out in centres located in the Global South but owned by these headquarter firms. The output of these centres is also owned by the headquarter firms. To take advantage of the much lower cost of scientific and technical personnel in India, many headquarter firms have located some of their R&D centres and business processing centres, called Global Capability Centres (GCCs) in India. But the ownership of the resulting patents and knowledge products is that of the headquarter firms. The result is a decreasing share of local ownership of patented knowledge produced in R&D centres in India, reaching a low of 20% in 2022 (Lee, Kim and Lee, 2024: 77).

Thus, the flow of knowledge to the Global South is restricted to less knowledge-intensive parts of the production system. More knowledge-intensive tasks and those that involve a higher share of tacit knowledge are enclosed in the Global North, and their deployment is protected through intellectual property rights. The knowledge task of development is a process of catching up in knowledge-based technological capabilities and advancing to the creation of new products, which may involve knowledge of the application of some hitherto unused, even in extreme cases of unknown, principle of nature.

Catching up in Technological Capabilities

The process of catching up in technological capabilities was characterized by Lall (1995) as falling into three stages: (1) basic technological capabilities, developed through experience-based learning or Arrow's learning-by-doing; (2) intermediate technological capabilities, which are assimilative and adaptive involving some search-based and related forms of R&D; and (3) advanced technological capabilities, which are research-based and involve process and product design. This deals with both the supply of and the demand for knowledge and technology, or knowledge as both an output and an input. Different technological capabilities are outputs of the knowledge economy, comprising enterprises, the state, and other components. They then serve as inputs into the economic system, raising its productivity.

In addition to Arrow's learning-by-doing by workers, catching up in technological capabilities also requires firm-level investment for the development of managerial and workforce capabilities. In GVCs, it is often observed that without initiating any technological change, supplier firms may advance from basic assembly or manufacture to enhancing knowledge and capabilities in management functions, such as undertaking supply chain management, including sourcing inputs and even carrying out detailed engineering. This is referred to as the shift from 'cut-make-trim' in garment manufacturing to full package supply. This basic managerial capability requires little R&D. In addition, there are incremental innovations, often process improvements, that are also not based on R&D and have been called 'innovation under the radar' (Fu 2020). There are also frugal innovations, based on knowledge of economising the use of resources, referred to as jugaad (or 'make do') in India.

The second modification, or rather, elaboration of Lall's schema concerns intermediate technological capabilities. This is assimilative and adaptive, but can also include reverse engineering, i.e. the copying or re-creation of technology that was either purchased or acquired through collaboration. There is an important role for R&D even in technological learning, especially when technology has more tacit than codified knowledge, with universities partnering with production firms as sources of both tacit and codified knowledge (Fu, 2015).

Stages of technological development, however, may well be telescoped. Late-comers can both absorb technology and move up the ladder, as was very likely the case with China's rapid technological advance after 1990. A deliberate strategy to achieve technological goals with adequate investment at both private and public levels can speed up the process. With the advent of AI, the absorption of technological knowledge and even reverse engineering will certainly be carried out much faster than it was even a few years ago. But it must be stressed that there must be deliberate micro- and macro-level strategies for such absorption and advancement.

Thus, the move to improved managerial capabilities or to intermediate and advanced technological capabilities requires upgrading strategies of firms, along with supportive national knowledge capabilities, and links among the different circuits of knowledge. But the critical part, signifying an upgrading strategy, is firm-level R&D. Public sector R&D usually plays a large role in national research spending (Mazzucato 2014), but firm-level R&D expenditure is what tells us about firms' strategies for upgrading in value chains. Thus, there is a need for both firm-level and country-level strategies for upgrading leading to policies for knowledge acquisition and development, which becomes the basis for innovation.

This movement of knowledge development toward technological upgrading would be somewhat different in the case of material processing, particularly in the processing of agricultural materials such as cocoa, coffee, or oilseeds. This processing differs from putting together materials, as in manufacturing. As a result, the way countries and firms upgrade their processing of agricultural materials could differ from the way they upgrade in manufacturing (Perez, 2008). Processing, as in the roasting of coffee beans, requires very different knowledge sets from those required for cultivation. Further, while cultivation can be carried out at the small-scale, household level, processing, packaging and marketing are scale-sensitive activities and require industrial-level organisation for efficiency and cost-effectiveness.

Knowledge and Vertically-specialised Development[2]

In a value chain framework, the problem of development can be framed as advancing from low-knowledge to high-knowledge segments of the production process. High-knowledge segments, as pointed out above, are also those that earn high profits.

The analysis of knowledge-driven development starts from a micro-economic firm-based analysis of GVC production segments. At the micro-economic or firm level, the knowledge base of production is related to the profits earned – merely competitive profits are earned when the knowledge base is relatively simple and many firms can enter the segment, as

[2] The term vertically-specialized development is due to Milberg and Winkler (2013).

in assembly (whether of garments or electronic products); there are limited process profits by firms that carry out process innovations of the incremental variety or functional upgrading to full-package supply with a medium knowledge base; finally, profits are high where major innovations in products are carried out with an enclosed high-knowledge base. The last would be the situation of Schumpeterian monopoly profits.

From the firm level, one needs to move to the economy. This can be done by aggregating different kinds of firms at the economy level (Milberg and Winkler, 2013. Here the hypothesis is that a low-income economy is vertically specialized in having a predominance of assembly-level firms, or production of agricultural raw materials; a middle-income economy is less-specialized in having a dominance of firms carrying out multiple functions as full package suppliers and involved in incremental process improvements; and a high-income economy is again vertically specialized in having a preponderance of firms involved in major product and process innovations of the Schumpeterian type and correspondingly earning high profits. Preponderance is in terms of the contributions of different types of firms to national income.

This is the macroeconomic counterpart to the Smiley curve, first formulated by former Acer CEO Stan Shih to illustrate that Acer needed to shift from low-value-capturing production to high-value-capturing design and branding (Shih 2010). Milberg and Winkler (2013) find some evidence for the economy-level Smiley curve in a cross-country comparison. They plot vertical specialisation against GDP per capita and find that both LICs and HICs are specialised. It is the MICs that are the least specialised: "… low-income countries seek to upgrade by reducing the overall level of vertical specialisation (raising domestic value added in exports) and then reach a point where rising incomes involve increasing vertical specialisation while focusing on the highest value added components of the GVC" (Milberg and Winkler 2013: 308-309).

Vertical specialisation can also be related to the routineness or otherwise of tasks performed in different GVC segments. Tasks can be divided on the basis of their routineness – routine tasks are performed according to specific, well-defined rules, while non-routine tasks, such as creative problem-solving and decision-making, entail more complex activities and tacit knowledge (Acemoglu and Autor 2010; Autor 2013). One would expect LICs to be specialised in routine-intensive tasks, HICs in non-routine tasks, and MICs somewhere in between, combining both.

What does this mean for knowledge strategy? To increase per capita income, a country needs to increase productivity by developing knowledge of non-routine tasks in sectors where it is already performing primarily routine tasks. The transition from assembly to full-package supply depends on developing the capabilities to perform non-routine tasks, whether in input logistics, design, branding, or marketing.

In each case of structural transformation, i.e., from low-income (LIC) to middle-income (MIC) and then to high-income (HIC) economies, the economy needs to develop knowledge-based capabilities to achieve the transformation. This then provides us with the objective of knowledge strategy – to develop the knowledge base for the structural transformation of the economies of the Global South, moving from basic technological capabilities to intermediate and then to high technological capabilities (Lall 1995). As a policy, this would require developing knowledge-based capabilities for firms and economies to move from production segments that deploy easily acquired knowledge, which allow ease of entry, to production segments that require knowledge that is complex, moving from know-how to know-why. In GVC terminology, it is lead firms that perform these tasks, meaning supplier economies need to develop lead firms.

However, rather than see knowledge levels as merely correlated with development levels we take the position that knowledge is the critical input that leads to development from LIC to MIC and then HIC. To make the model endogenous, we need to see how knowledge is created as an output in the economy and then becomes an input to development. Since innovation is based on knowledge, even if incremental knowledge, we can agree with Xiaolan Fu that “Innovation is not the outcome of development; rather it is a means for development. Innovation is not a characteristic of rich countries; rather, without innovation of the type we captured [incremental, mainly process innovation] there will be no development from low income to middle income” (2020: 329; words within square brackets inserted by author).

Regarding the movement from MIC to HIC, as discussed in detail in Nathan (2024), it is necessary to develop the knowledge base for high technological capabilities that can enable basic, not merely incremental, innovation in products. New products, however, often involve new principles of nature; thus, a well-developed science and technology research system is needed to move from MIC to HIC. We now discuss in more detail how knowledge drives upgrading.

How Knowledge Strategy Drives Technological Upgrading

Technology absorption is not just a matter of operating it but of understanding it. Understanding the what of operating technology is enhanced by knowing the why of that technology, which is acquired through the firm’s R&D. Taking garment manufacturing as an example, firms start by just assembling garments, or what is called ‘Cut-make-trim’ (CMT). But adding functions, such as sourcing fabric, making samples of different types, and so on to these basic tasks, allows them to move from the CMT to becoming “full package” suppliers. This also involves acquiring knowledge-based capabilities across the industry and increasing domestic value addition. However, due to the monopsony structure of GVCs, manufacturers do not seem to earn higher rates of return; instead, they benefit from larger scale (Nathan et al., 2022). Similarly, for agricultural products and even minerals, firms can move up the value chain by undertaking processing rather than selling the basic raw materials, as Indonesia has done with minerals used in the production of solar panels (Oxford Business Group, n.d.).

All the above innovations are process innovations, based on knowledge that is not new to the world but new to the firm. However, they require deliberate, firm-level strategies to acquire knowledge. These need to be supported by state interventions. First, in the provision of basic education so that an educated workforce becomes available for employment. Second, in setting up industry-specific training institutes, such as India's National Institute of Fashion Technology (NIFT), to provide technical personnel to support upgrading in GVCs.

Next is the development of intermediate technological capabilities. Some of it, such as the movement toward full-package supply, is the result of the aforementioned processes. But there is an important role for knowledge strategy in reverse engineering in developing intermediate technological capabilities. The knowledge base of reverse engineering is acquired through R&D at the firm and product (industry) level. A good example is that of the development of India's generic pharmaceutical industry. Since patents describe the basic formulation of the drugs, these could be reverse-engineered to produce non-patented, thus cheaper, generic versions of the drugs. India's pre-WTO patent laws, which allowed only process patents, not product patents, promoted such reverse engineering. In the early part of the twentieth century, Japan was well known for reverse engineering products, machines, and equipment from the West (Suzuki, 1994). Reverse engineering requires strong support from R&D, both within firms and across the industry, as well as strong links among different knowledge circuits and networks.

Intermediate technological capabilities also include incremental innovations. They also include the provision of high-value services, such as IT software services, which became a cornerstone of India's trade strategy, though they are now under threat with the development of AI substitutes for routine and even non-routine IT tasks.

Completing catch-up, which is what the development of intermediate technological capabilities requires (1) firms that develop strategic capabilities, that is look beyond existing business models to newer markets and possibilities in the near future; (2) firm-level investment in R&D; (3) public investment in universities and research institutes; and (4) links between the different knowledge circuits, such as between firms and research in universities.

All of the above require a competitive and relatively open economy, in which firms are forced to operate at the technological frontier. South Korea achieved this in the pre-WTO period by linking industrial policy subsidies with export performance (Amsden, 2001). China, though a relatively protected economy, has experienced high levels of domestic competition among province- and city-based firms (Breznitz and Murphree, 2011). India, on the other hand, with a relatively closed economy and strong duopolistic production structures, has not pursued a strategic push to reach the technological frontier, as reflected in low levels of firm R&D expenditures (Nathan and Rahul, 2026). China also had a policy of using access to its large domestic market to secure transfer of technology from investors from the Global North. But turning this transfer of technology into technological capabilities required both firms that competed for markets and the resulting push to be at the technological frontier.

Moving from the technological frontier to pushing it forward is a big step; in knowledge terms, it is a move from being a user of knowledge to creating it. The difficulty of making this transformation accounts for the Middle-Income Trap – it is relatively easy to catch up on technological knowledge but more difficult to create new technological knowledge. This is the non-linearity in the knowledge system.

To illustrate the shift from using knowledge (along with reverse engineering and incremental innovation) to creating knowledge and products, we provide a few examples. After the Plaza Accord between Japan and the USA, which led to an appreciation of the Japanese Yen, the Japanese shifted from supplying cheap cars to manufacturing better (e.g., more fuel-efficient) cars (Suzuki, 1994). After the East Asian financial crisis of 1998, Korea focused on product innovation in short-cycle technologies, such as consumer electronics (Lee, 2013). Such shifts require creative insecurity (Taylor, 2016), in which markets with established products are at risk, and firms have to change their business models.

There are both macro and micro factors at work. At the macro level, competition in the world market. At the micro level, firms require strategic capabilities to change business models. This is evident in China's advances in electric vehicles. At the macro level, the government concluded that the country could not compete in the conventional-fuel vehicle market, so it decided to support electric-vehicle production through various incentives. Chinese automobile and battery manufacturers, such as BYD, now the world's largest electric-vehicle manufacturer, adapted their business models to focus on electric-vehicle production.

Firm-level R&D is critical in both reaching the technological frontier and advancing it. A recent McKinsey (2026) report on the electrical goods industry noted that Indian manufacturers in this sector invested only 1 per cent of revenue in R&D, while Chinese manufacturers invested 2 per cent. It is no wonder that the McKinsey report identifies the low quality of Indian electrical goods as a barrier to increasing their exports.

The low level of firm-level investment in R&D is a general feature of the Indian economy. In a situation of already low national investment in R&D at around 0.65 per cent of GDP, private-sector R&D contributes only 30 per cent of R&D in India, compared with 60 per cent in both China and South Korea (for details, see Nathan and Rahul, 2026). This is so for large enterprises too. The important question is why large Indian firms do not have a culture of investment in R&D? The reason is that there is not that creative insecurity as would exist in an open economy with competitive markets. It is not just overall tariffs, but the use of anti-dumping tariffs and so-called quality control measures that support monopolies, that underlie the low investment of the Indian private sector in R&D, meaning that attention is not paid to knowledge as an input. The contrast with China, despite somewhat similar tariff rates, is that it has a system of intense internal competition, which will be brought out in Section 5 on the political economy of technological competition.

A word about knowledge strategy and technology development in small economies. They cannot be expected to cover as wide a range of knowledge and technology domains as large economies can. They will have to concentrate on certain domains and build world-class capabilities in them. For instance, Finland has a special capability in designing and building icebreaker ships. With the Arctic region opening for potential navigation, this capability makes it important to world trade. Better known specialization is that of Taiwan and its critical knowledge of chip manufacture, providing what has been called a "silicon shield." Besides specialising in niche areas, small economies can also build regional partnerships in knowledge domains to overcome the disadvantages of narrow scope.

4: Knowledge Networks

Having identified the tasks to be addressed by knowledge strategy in the movement from low- to middle- and then to high-income economies, we now turn to how the knowledge economy needs to be organised to perform those tasks. We move from the *what* of knowledge strategy to the *how* of knowledge policy, with discussion concentrating at the meso level of the knowledge economy.

Our main propositions in this Section are that (1) knowledge is produced in networks; (2) together the internal structure of nodes and their network connections result in the emergence of some nodes as central hubs in the global knowledge structures; and (3) knowledge networks, through feedback loops and preferential behavior, lead to increasing returns in knowledge and result in a Paretian power law distribution of nodes in a "winners take most" manner in global knowledge networks.

Social Character of Knowledge Production

The creation of knowledge may be thought of as the output of individuals working in isolation or of the heroic, usually male, scientist. Individuals are certainly important and play crucial roles in the creation of knowledge, but network theory emphasises that this work is carried out by individuals in relation to other individuals, groups, or even networks. The individual scientist not only stands on the shoulders of earlier giants in the field but also draws ideas from thinkers in other fields.

A network analysis of knowledge creation involves a consideration not just of the attributes of knowledge actors and organisations but also of their relations or links with other actors and organizations, either within the node or within other nodes. Consequently, a network theory emphasises that knowledge is not created solely by the characteristics of actors, whether individuals or groups, but by actors in relation to or connected with other actors, within and across nodes, i.e., networks. Further, knowledge networks, like many other networks, are multi-level (Contractor et al., 2001), with, for instance, networks in the university-based creation of knowledge and networks in the application and refinement of this knowledge in firms.

Networks are not only transmission mechanisms but also sources of new ideas (Ferguson 2018: 42). Ideas from one knowledge domain can be transferred to another, a transfer that depends on the existence of network connections. In a famous example of the transfer of an idea from one domain to another, Darwin points out that his idea of fitness in natural selection is "… the doctrine of Malthus, applied to the whole animal and vegetable kingdoms" (1859/2022: 10). While it is justly the Darwinian theory of evolution of species, we should not ignore the contributions of Malthus the economist. This shows the importance of connections in enabling the transmission of knowledge from one domain to another and its application in that domain.

While the above explains the connections between the works of two individuals, in the contemporary world there is explicit collaboration among groups and formal teams in the creation of knowledge. A paper by Stefan Wachty, Benjamin Jones, and Brian Uzzi (2007) analysed 19.9 million research articles and 2.1 million patent records from 1955 onwards and found that teams increasingly dominate knowledge production.

Knowledge Networks

There are some stylised facts about knowledge which we need to consider in explaining and understanding knowledge networks:

1. Knowledge networks are increasing in scale as new centres or nodes of knowledge creation emerge.
2. Different countries/economies have emerged as hubs of advanced technological knowledge of the era, e.g., Africa, China and India, the Ottoman Empire, then Western Europe, and later North America. Who's next?
3. Some hubs, those that are centres of advanced technological knowledge, have many more connections than others.

A knowledge network is not homogeneous, i.e. it is not a network in which all nodes have an equal number of connections (e.g. with adjacent nodes on either side). A homogenous network does not align with the stylised fact that hubs have a strong inequality in the number of connections they have globally. Silicon Valley, for instance, clearly has many more connections with both those who use its knowledge creations and those who provide inputs to the hub than, say, Lucknow or even Bengaluru in India.

Thus, a knowledge network must essentially be considered heterogeneous, in that some hubs have more connections than others. Technically, this is called a scale-free network, meaning its growth or scale is not limited by the network's average degree. The structure of a scale-free network is formed by just two factors – the creation of new nodes and the preferential attachment behaviour of nodes (Barabasi and Albert 1999).

The creation of new knowledge nodes, however, is not only a matter of the attributes of these nodes but also of their networked relations with other nodes. Further, the development of nodes and connections is key to transforming knowledge into innovation, through the links between knowledge-creating and knowledge-using nodes.

These connections, as between theory and practice or knowledge and innovation, require feedback loops. Not only does theory inform practice, but practice, in turn, informs theory, resulting in a feedback loop that can refine knowledge over time. Innovation can, in turn, increase knowledge as the contours of the application become clearer and even change. The existence of such feedback loops means that the outcome cannot be predicted from the initial effort or investment. As a result, there is a non-linearity in the relationship, leading to increasing returns in knowledge creation. Knowledge networks that are efficient in feedback relations will experience a faster increase in knowledge outcomes than those that are less efficient in these relations. The importance of feedback relations has been analysed in network theory in terms of strong and weak links and structural holes, concepts to which we will return later.

Adding a fitness criterion to each node describes its ability to compete for connections (Barabassi 2009). The fitness criterion for knowledge networks can be that of patents. This fitness criterion can also lead to later nodes with, say, more patents overcoming the "older, but less fit node" (Barabasi 425).

Preferential attachment of other nodes increases the centrality of some nodes, creates multi-scaling, and results in a hierarchy of nodes, where some nodes have many connections, while many others have few. Nodes with many connections, through which other nodes connect to one another, become hubs, as in the hub-and-spoke model of logistics. The hubs are also super-connectors. The creation of new nodes and preferential attachment behaviour together result in a Pareto power-law distribution of outcomes, where the knowledge outcomes are concentrated in a few nodes, while many nodes have few outcomes.

Taking the fitness criterion indicator for a knowledge hub to be the number of patents, we obtain a power-law distribution, as shown in Fig. 1, which shows the number of international patent applications (PCT) in 2020 and 2025 for the top 10 countries. Even among the top 10 countries, there is a power-law distribution, not a normal bell-shaped distribution. If we were to extend this figure to include all countries, the power-law distribution would be even starker – few have many patents, and many have few, if any. Within the top 10, China, the USA and Japan are clearly ahead of the rest in this 5-year period, while South Korea and China are also increasing their numbers. India does enter the top 10 list even in 2025.

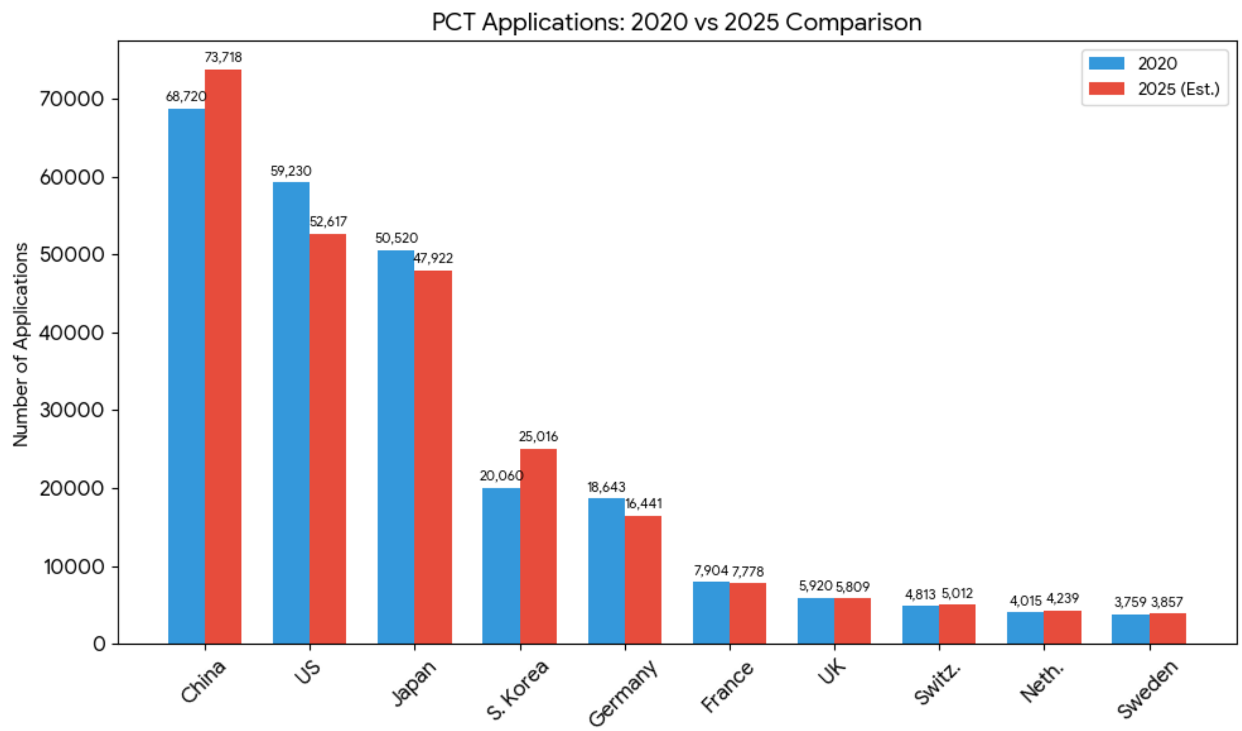

Figure 1: Power-law distribution of international patent applications (PCT) by the top countries in 2020 and 2025

Data Source: WIPO Annual Reports, 2020 and 2025, as shown in a figure by Google-Gemini.

Barabasi and Albert (1999) argued that new nodes are likely to attach themselves to nodes that already have several connections. This is the preferential attachment that leads to the “rich get richer” or “winners get most” phenomenon. Knowledge creation, measured by patents, serves as the basis for attracting new connections. Nodes with the most patents are likely to have the most connections.

How Nodes Become Highly Creative

The discussion of the Needham question (why did the scientific revolution not take place in China or India?) has centred around the internal characteristics of these countries as knowledge hubs that fostered or impeded scientific discovery. However, network theory suggests that the knowledge outcomes of hubs are shaped not only by their internal characteristics but also by their connections to other hubs and nodes. We will look at some of both the internal features of highly creative nodes and their network connections.

The denser, more diverse, and better-connected nodes are, the more likely they are to be creative and innovative. Hidalgo (2015) argued that the strength of networks depends on their size and diversity. Network size increases with the number of connections, creating feedback loops that can amplify knowledge. The size of networks increases when experts and laypersons use the same language, as was the case in early modern England, where laypersons and skilled workers also attended scientists' lectures (Jacob, 2014). There was a vernacularisation of science in Europe as Descartes, Bacon and Galileo all wrote in their respective vernaculars (Pollock, 2011: 7).

Coleman (1988) held that the size of networks depends on the extent of both strong and weak social connections. Studies cited earlier show that knowledge is the creation of collective relationships between individuals and various kinds of collectives organised into networks. An epistemic community formed of those practising a particular discipline is one such collective. Such epistemic communities could be dense networks, in which every node has nearly the maximum number of connections to other nodes, rather than sparse networks with only a limited number of connections.

In making networks more extensive and denser, trust and social capital are essential, making it cheaper for networks to form and expand; their absence may lead to unconnected nodes, thereby weakening the network. E.g., there may be a lack of connections among engineers and workers in a factory, between research centres and firms in an industry, between castes/ethnic groups, or between genders. Ebadi and Utterback (1984, cited in Phelps et al., 2011: 13) demonstrate that network cohesiveness, centrality, and diversity of communication are all positively related to innovation, i.e. the application of knowledge.

A central node has connections with more nodes. How does a node become central in the knowledge network? It does so by fulfilling the fitness criteria for being a knowledge creator, which, in turn, relate to the node's internal network structure and its ability to absorb and utilise knowledge from network connections. This internal structure can lead to increasing returns or non-linearity in knowledge creation. Having become a central node, it also has access to more, richer and more diverse knowledge or information, thus increasing its potential "to learn from the network and synthesize and recombine knowledge into novel ideas" (Phelps et al. 9, citing Burt 2004; Ebadi and Utterback 1984: Morrison, 2002).

The critical question is: how does a knowledge node or hub become central in the worldwide knowledge network? In network terms, this can be stated as: what is the fitness criterion for a node to become central in a knowledge network? The fitness criterion would vary from one domain to another, such as in the arts or social sciences. In the knowledge network, this is a matter of being or becoming a knowledge creator. Whether a node or hub becomes central depends, in turn, on the ties within the hub or its internal structure and the pattern of ties with other nodes.

Meeting the fitness criterion of role in knowledge creation is not only a matter of network roles and structures; network theory has much to say about this. Hubs, or even nodes, of knowledge actors are themselves structured by networks, and these structures can affect knowledge creation. Furthermore, they have connections to other nodes or hubs, and these ties also help knowledge actors contribute to knowledge creation.

There are other non-network features that characterise well-functioning knowledge nodes that create knowledge. Some of these include challenging accepted theories in a manner akin to Thomas Kuhn's analysis in *The Structure of Scientific Revolutions* (1962), whereby old theories or paradigms are replaced by new ones, a process that itself depends on adopting a cosmopolitan attitude towards acquiring knowledge from other, newer, and more diverse nodes. Further, there should not be religious, state, or even peer authorities dicta preventing the incorporation of counter-results and the overthrow of older paradigms. Any empirical formulation is subject to verification (Popper, 1959). Consequently, knowledge systems will necessarily change and cannot be held immutable or required to conform to religious or political tenets.

In this brief discussion of a complex topic, we can point out that diversity of domains and the intensity of connections, combined with a cosmopolitan attitude to drawing on influences from other networks, are important in the development of knowledge networks that can be creative and incorporate change. Simultaneously, there is a need to be willing to change paradigms without state, religious or even within-discipline constraints.

Weak Links and Structural Holes

We can examine the relative influences of uniformity and diversity on knowledge creation by drawing on the distinction between strong and weak ties (Granovetter, 1973). Strong ties or links between nodes are those with significant overlap in contacts and may involve multi-stranded relationships. With strong links, there could be substantial sharing of ideas, as in an epistemic community. However, since the set of questions addressed or experiences shared would be similar, there would be considerable redundancy in the exchanges and in the community's overall knowledge.

Strong ties are also defined by high communication frequency, long duration, and affective attachment (Marsden and Campbell 1984), which are better than weak ties in knowledge transfer (Uzzi and Lancaster 2003). This facility of strong ties in knowledge transfer is particularly true for tacit knowledge, which is built through experience and requires intense, prolonged interaction to be transferred (Phelps et al., 2012: 18 and 38). However, network density (i.e., a high number of connections per node), along with diverse members from different fields of knowledge, leads to greater knowledge creation (Reagans and Zuckerman 2001, cited in Phelps et al., 2012: 17).

Weak ties, on the other hand, refer to those that exist between different groups, such as between different epistemic communities, say, those of economists and evolutionary biologists. The relationship may not be multi-stranded or regular. However, such weak ties can connect communities with diverse experiences and knowledge, thereby facilitating the exchange of novel ideas. This exchange of novel ideas fostered by weak links between different nodes was what led Granovetter to refer to the "strength of weak ties", as in the paradoxical-sounding title of his 1973 paper on the topic.

Weak ties can range from college canteen contacts between students of different disciplines to office staff gathering around the water cooler or coffee machine, or, nowadays, digital groups of various types. The strength of weak ties lies in their ability to transmit knowledge across disciplines or between groups with complementary information. Marshal pointed to the role of clusters, with strong ties of connected nodes in a locality, in transmitting knowledge within a field or an industry. This is akin to the role of dense or strong ties in creating and transferring knowledge within a cluster or small-world network. Other work, such as that of Jane Jacobs (1969), however, points to the role of complementary sets of knowledge in fostering creativity. While Maryanne Feldman and Jongmin Choi (2015) mention studies that show the importance of diversity over uniformity in promoting creativity.

It, however, is not necessary that there be links between different nodes in a network, or even between different networks in a multi-network system. The absence of links between different groups or communities was conceptualised by Ronald Burt (2004) as *structural holes* in a network. In a sense, this is weak ties carried to the logical extreme of the absence of ties. Much work has been done on structural holes, mostly regarding the lack of connections within an organisation and the role of those labelled as structural hole spanners, i.e., actors who act as brokers connecting complementary knowledge or information nodes (Lin et al., 2021).

For our purposes, the theory of structural holes is important in highlighting the possible lack of communication and, thus, the non-transmission of ideas between nodes with complementary knowledge or information. Complementary knowledge could be, for instance, between those propounding a medical theory and those carrying it out in practice. A structural hole would result in the failure to transmit experiential or experimental knowledge from applying a medical theory to those formulating theory. Alternatively, there could be a disjuncture between engineers proposing a production system and workers on the shop floor carrying it out, as well as between designers of household equipment and their mainly female operators. Or, between research centres and firms in an industry. The analysis of the role of consumers, or lead consumers, in the democratisation of innovation (von Hippel, 2005) suggests the possibility of filling structural holes in the lack of relations between different actors, organisations or even networks to improve product knowledge and innovation. Where no link exists between different circuits of knowledge, the resulting structural hole would constitute a weakness in the knowledge network or hub and retard its creativity.

Epistemic Communities as Small-world Networks

An epistemic community is an example of a small-world network. A small-world network is highly clustered, i.e., has nodes with similar knowledge interests, and has short distances in terms of degrees of separation between nodes.[3] Small-world networks can be efficient in developing well-defined domains of knowledge and even in transmitting tacit knowledge acquired through experience, e.g., knowledge of data sources and their limitations for answering different questions. Thus, an organisation specialising in labour studies could develop a strong capability in this domain, with much of the implicit knowledge shared among its members.

While acknowledging the possibilities for cooperative relations among actors in small-world networks, we should also recognise that competition exists among these actors. Within epistemic communities, there is competition to be first or to be the creator of a novel idea. Darwin, who for many years had been developing his evolutionary theory of the origin of species, was supposedly spurred to complete and publish it when he learned that Wallace was working along the same lines. Competition could even lead to the concealment of information or ideas to secure a first-mover advantage. There could be cliques within small-world networks. Small-world networks would exhibit both cooperative and competitive relations, as in all human networks.

Standpoints and Knowledge Creation

Actors in a node may be within a heterogeneous structure, divided by caste, class, etc. Is knowledge creation affected by the social position of actors? We can examine the effects of different standpoints on the knowledge created and applied in innovation in production. Due to lower per capita incomes, firms in the Global South generally face small markets for high-price products, while there are large markets for low-price products. This leads to market pressure to design low-price products that economise on product features and materials.

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[3] The term "small-world network" originates from the theory that there are no more than six degrees of separation between any two persons on Earth.

On the other hand, firms in the Global North, with economies characterised by higher per capita income, do not face such pressure to pare down their products or compromise on quality. This difference has led firms in the Global South to undertake what has been termed "frugal engineering" in India (a term coined by Carlos Ghosn, then CEO of Renault-Nissan). Of course, such technological innovations, even if incremental, are based on modifications to the systems of knowledge embodied in the products. This suggests that firms' market position, whether in high-income or low- to middle-income countries, can influence the knowledge they create.

Similarly, consumers may have a different perspective on products than producers do. This necessitates that producers establish network links with consumers or lead consumers (von Hippel, 2005). This is so for developing production-related knowledge, particularly of the incremental variety.

Whether such different standpoints would affect knowledge creation in more basic knowledge, such as in the sciences, is a moot question. The human experience or relation to basic systems of scientific knowledge may vary with groups of actors. Many have argued against the objectivity of the knowledge standpoint “from nowhere”, as in the Cartesian view; since the Heisenberg uncertainty principle contends that the very act of measurement can affect the object being measured, so that there is no fully objective measurement of a phenomenon. This means that we must incorporate reflexivity into the analysis of both natural and social phenomena.

In the social sciences, however, there is a stronger argument about the influence of a knowledge actor's standpoint (see Sandra Harding, 2013, and its application in the analysis of witch hunts in Kelkar and Nathan, 2020) on the formation of knowledge. The standpoint of the supposed victims of witchcraft varies from that of the actual victims of witch hunts. The former group argues for the existence of persons who use supernatural powers to cause harm, while the latter group challenges the very existence of such supernatural powers and calls for empirical evidence of their use of such powers. This is a contest between two different forms of knowledge formation; one based on belief and the other on empirical verification.

Another example from economics can illustrate how standpoints influence the development of knowledge. Economists from the advanced industrial economies, starting with David Ricardo, have based their analysis of international trade on the assumption of a free flow of technological knowledge between economies. On the other hand, economists from then-non-industrialised countries, such as Alexander Hamilton of the USA and Friedrich List of Germany, based their analysis of international trade on the exclusion of non-industrialised economies from the advanced technological knowledge of the day (Ha Joon Chang, 2000). Thus, the roles of power and standpoints within network hierarchies are worth considering in analysing factors affecting not only knowledge diffusion but also its creation.

Power and Exclusion

We have seen that knowledge networks can be unequal and subject to a power-law distribution of the "winner takes most" type. Forms of exclusion from advanced knowledge, through intellectual property rights and social norms, exacerbate the power-law distribution of outcomes in knowledge creation. Exclusion reduces the flow of knowledge from central to peripheral nodes. At the same time, new nodes capable of competing in knowledge creation can increase their centrality and, over time, even become super-connectors.

What network analysis of knowledge reveals is the unequal distribution of knowledge outcomes, creating knowledge hubs. As we saw earlier in Figure 1, a few hubs account for most patents, while many are positioned in the knowledge hierarchy as users of advanced or not-so-advanced technology. However, for this to result in unequal income distribution, another factor is required – the unequal valuation of knowledge in different hubs; in a sense, there must be a *de facto* knowledge theory of value, where the returns to widely distributed knowledge, such as cooking, are lower than returns to not-so-widely distributed forms of knowledge, such as mathematics or science.

There are no human hubs (or even hubs of non-human sentient beings) that do not embody some form or extent of knowledge. However, there may not be an equal valuation of knowledge in these different hubs. Take the gender-based distribution of labour that creates a distribution of knowledge or capabilities. As Adam Smith pointed out, it is the division of labour that creates different capabilities, not the other way around (Wikipedia, https://en.wikipedia.org/wiki/Division_of_labour).[4] When we apply this to the gender-based distribution of labour, it creates a hierarchy between knowledge in household and in income-earning tasks. There is no reason inherent to the nature of the two kinds of knowledge that results in the low valuation of household compared to income-earning tasks. This differential valuation results from an economic system in which earning income is valued more highly than performing domestic tasks, though both may be equally necessary for the functioning of a household.

In capitalism, knowledge supported by intellectual property rights creates monopolies, which may be referred to as knowledge (or intellectual) monopoly capitalism (Pagano 1995), earning monopoly profits or a surplus of profits above the cost of production. On

[4] That capabilities are created by the division of labour was brought home to me when my wife, Govind Kelkar, pointed out that she was not born with childcare capabilities and that, I too, could acquire the same capabilities.

the other hand, non-monopolised knowledge, or knowledge that is easily acquired (or of an earlier technology vintage, as is usually transferred through foreign direct investment), earns only normal profits over the cost of production. Taking there to be degrees of monopoly rather than a simple binary between monopoly and competition, the economic valuation of knowledge by degrees of knowledge monopoly creates a hierarchy of profit rates and incomes.

What the above means is that the network features of knowledge cannot, by themselves, result in inequality in income or status. There can be a hierarchy in terms of the creativity of knowledge hubs. But features of enclosure of knowledge and unequal returns to different forms of knowledge must be added to knowledge hierarchies to transform them into income or status inequalities.

At a millennial historical level, I would put forward the thesis that the enclosure of knowledge, and thus the constriction of its spread, is a feature of the world capitalist economy, beginning in early modern Europe around 1400CE. Before that, there surely would have been first-mover advantages for societies that innovated in knowledge and technology, and probably even attempts to maintain secrets; but the spread of the era's advanced knowledge was not for long confined to the initial creators. The result was that inequalities were less substantial in the pre-capitalist eras, as noted in the paragraph quoted in Section 1 of this Element from Maddison (2007). It was with capitalism and its intellectual property rights system that first-mover advantages in scientific knowledge were multiplied by increasingly stricter forms of exclusion and the differential valuation of monopolised as against non-monopolised knowledge.

5: Political Economy of Knowledge Creation[5]

Analysis of the knowledge economy, including the use of network theory as attempted in the previous Section, essentially deals with the process or the *how* of knowledge creation. However, there is also the question of the *why* of knowledge creation: why do some economies place more stress on knowledge creation, measured in the contemporary period by the proportion of GDP spent on R&D, than others (Taylor 2016)? In attempting to answer this question, we must go beyond network analysis to examine the forces that drive networks. We will examine this question within the context of the pre-modern and modern periods of capitalism. The answers may be relevant to earlier periods of world history, but that is not a claim made in this Element.

Our main propositions in this Section are that: (1) strategic insecurity, economic and political, has been a spur to knowledge creation (Taylor, 2016); and (2) hubs that dominate knowledge creation in the general purpose technology of a capitalist era are able to translate knowledge domination into economic polarity in that age.

Strategic Insecurity as Spur to Knowledge Creation

One early manifestation of the knowledge divergence between what we now label the North and the South was the military revolution in the pre-colonial period (Parker 1996). Of course, as with all other analyses, there is considerable debate over whether a military technological revolution led to the defeat of the major Asian powers and the rise of Europe. However, the Chinese post-Opium Wars modernisation "Self-strengthening" movement was clear that the reason for China's subjugation was its having fallen behind the West in military technology (Kroeber, 2024). A recent analysis of India's defeats also attributes it to its "lag behind in military technology" (Kumar, 2025: 269). Why did the major Asian powers fall behind Europe in military technology?

The European powers that spearheaded colonisation were seafaring countries. They competed among themselves for mastery of the seas. During this competition, they developed cannon-carrying ships. The main Asian empires, those of China and India, were land-based empires. They did not focus on the development of naval power and were, thus, quite unprepared for a challenge that came not over land but across the seas. The Arab and Indian vessels proved no match for the Portuguese "men-of-war" in the early 1500s (Abu-Lughold, 1989: 19), and later the decimation of the Chinese fleet by European cannon-bearing ships during the Opium Wars was a stark demonstration of Asia falling behind Europe in what became a crucial sphere of knowledge in naval technology. What spurred this advance in technological knowledge was competition

[5] This section owes much to two papers (Nathan and Rahul 2025; and Nathan and Rahul 2026) done jointly with Rahul.

among the seafaring European nations. From this, we can identify competition among nations as a factor in knowledge creation and advancement.

Schumpeter identified competition among firms as the driving force behind the formation of knowledge-based monopolies, now labelled intellectual monopoly capitalism (Pagano, 1995), and as the primary force behind innovation in production—competition forces firms to strive to be at the technological frontier and to create knowledge-based monopolies. Thus, we have two types of competition, politico-military and economic, as the drivers of knowledge creation in the era of capitalism.

What this analysis, however, overlooks is that there is also simultaneous cooperation alongside competition. There are not only network-based flows of knowledge, but also explicit coordination across national networks, such as the international cooperation to decode the human genome or the multi-country particle accelerator CERN in Europe.

Capitalist economics tends to portray competition as the primary, if not the only, driving force behind knowledge creation. Capitalist firms do compete and try to form intellectual monopolies. However, there are clearly many individuals, groups and systems that are not driven by competition. Richard Dawkins, the theorist of the *Selfish Gene* (2016), points out that humans are the only species that can overcome genetic traits through developing social norms, such as altruistic cooperation. This would mean that even if selfishness or competition were genetic or endemic to humans, it could still be overcome by cooperation. The necessity of combining cooperation with competition in the global knowledge economy is something we will return to in the concluding section.

Long Waves of Techno-economic Paradigms

The capitalist world economy has been going through long waves of technological change, driven by knowledge. Technologies create or lead to techno-economic paradigms that include not only the input-output technological relations but also "organisational habits in technology, the economy, management and social institutions" (Perez, 2002: 7). Carlota Perez identifies five techno-economic paradigms of capitalism: Machine and Factory Production of the Industrial Revolution; Steam and Railways; Steel and Electricity; the Automobile and Mass Production; Information and Communication Technology (ICT) and Decentralized Production. We are now in the sixth techno-economic paradigm, that of Artificial Intelligence (AI).

The age of each techno-economic paradigm is identified by its core technologies and forms of organisation. The core technologies include a general-purpose technology (GPT) that is central to the set of technologies of that Age: mechanisation, steam power, electricity, ICTs, AI. Each Age also has its characteristic form of organisation of production – such as factory, mass production, splintered and decentralised production. The combination of technology and the organisation of production makes for a techno-economic paradigm. Each Age also has its characteristic environmental footprint (Kaplinsky 2021), a topic that has not been much researched.

In the transition from one technological paradigm to another, there arise opportunities for latecomers. The new technology requires new competencies that no economy may hold an edge in. This provides an opportunity for countries other than the current leaders to play a key role in developing the new technology. Consequently, there can be a shift in the technological leader. This happened in the shift from mechanisation and steam power to electricity and mass production, as the leadership of the technological core or the new general-purpose technology shifted from Britain to the USA. Of course, such a shift does not necessarily have to take place. Britain remained the leader in the shift from mechanisation to steam and steel, while the USA remained the leader in the shift from electricity and mass production to ICTs. Who will lead the shift from ICT to AI and quantum computing? There is clearly a race between the USA and China to be the leader in this technological development - and to enclose the technology so they can capture monopoly returns from it.

We could call the current age the Age of Artificial Intelligence (AI)**,** as in the title of the book by Henry Kissinger, Eric Schmidt and Daniel Huttenlocher (2021). The core of AI is machine learning, which itself has gone through many transformations, with the most important perhaps being that from “hand-crafted knowledge to machine-learning from data” (Russell and Norvig 2020: 52). It is certainly a general-purpose technology affecting not just all areas of production but even any intellectual task. In parallel, quantum computing is developing, which could work with AI to amplify the transformation of both civilian and military technologies.

The appearance of radically novel technologies, those that lead to a new technological paradigm, depends on “the constant capture of new natural phenomena and the harnessing of these for particular purposes…Technology builds out not just from combination of what already exists but from the constant capturing and harnessing of natural phenomena” (Arthur 2009:22). The capturing of natural phenomena goes all the way from using the heat of fire to quantum phenomena. For this reason, advances in radically novel technologies depend on scientific development.

Whether a techno-economic paradigm is in its installation or deployment phase affects the nature of the opportunities presented. In the installation phase, it is difficult for a latecomer to break in, since it requires a well-developed science and technology research system. It also requires large investments in scientific research and world-class universities to enable development. On the other hand, technology deployment, or its embodiment as innovation in products and services, which depends on the development of existing basic technologies or combinations of technologies, can be carried out without necessarily being at the frontier of scientific development. In the deployment phase, there are opportunities for what Keun Lee labelled short-cycle technologies, which he also described as “less original technologies” (2013: 140), or called second-generation production and process innovation (Breznitz and Murphree 2011). One can distinguish between technologies that represent a new technological paradigm, a radically novel technology, from one that continues along a given technological path (Dosi 1982), a formulation that fits in with the conception of successive techno-economic paradigms.

We now look at how technological competition between the US and China has been shaping and its effect on the world order. While the first part of this section deals with knowledge and technological competition as outputs of the economy, the next part examines how these become inputs into the world order.

China’s Overall Rise

That there was an overall upgrade in technological knowledge in China is argued by Antonin Bergeaud and Cyril Verluise (2022) based on the increase in the number of citations received by patents, which they take as an indicator of patent quality. As the authors point out, “Overall, the frontier technology landscape, once dominated by the US, Japan and Germany, now appears much more polarized between the US and China” (2022: 24). This was seen in the case of both patents and highly-cited research publications.

The overall rise of China in the creation of technological knowledge is seen in the analysis of top-cited research publications. Jennifer Wong Leung, Stephen Robin and Danielle Cave (2024) analyse highly cited research in 64 critical technologies and find that the US-China picture had completely reversed in just about 15 years, between 2003-07 and 2019-21.

Table 1: China’s Rise – Top Cited Research Publications, Ranks in 64 Critical Technologies

Country	**Leading in 2003-07**	**Leading in 2019-21**
China	3	57
USA	60	7
	Within Top 5	**Within Top 5**
Japan	32	8
South Korea	7	24
India	4	45

Source: Leung et al, 2024.

Table 1 clearly shows that China has advanced to lead in research output across 57 technological areas in 2019-23, while the USA leads in just 7. China has advanced on a broad scientific basis, having led in just 3 areas in 2003-07, whereas the USA led in 60 technological areas during that period.

What is important from the view of knowledge policy is that whether it is the US in 2003-07 or China in 2019-23, they led not just in one or two fields of technology, but in most of them – the US in 60 and then China in 57 technological areas. This shows that advances in technological knowledge tend to be broad-based rather than narrowly focused. One can say that there are links between improved capabilities across diverse areas of technology, leading to a broad-based advance; there are economies of scope with feedback loops that link advances across different domains.

The decline of Japan and the rise of both South Korea and India are also evident in the Table 1 above, though the latter two are only in the top 5, not leaders. While commentators, including some at the seminars at which this analysis has been presented, note that China has been gaming the system of research citations, nevertheless there seems to be a clear advance of China over the three decades of this century.

As mentioned in Section 4, it is important to note the simultaneous advances in many domains of scientific and technological knowledge. There are many spillovers from one knowledge domain to another, making for a broad-based rather than a narrowly focused advance. We now turn to the competition between the US and China in the critical general-purpose technology of Artificial Intelligence, which, we must emphasise, is a form of intelligence.

Artificial Intelligence and Technological Competition

AI and quantum computing, as well as climate change-related technologies, are novel, embodying newly analysed or newly used natural phenomena. The development of AI is based on machine learning, a novel technology that enables computer systems to learn without explicit programming (Russell and Norvig 2010). AI is a general-purpose technology (GPT), in the sense that it can be applied across every sector of the economy and, even, every activity in society and the polity. The nature of innovation and scientific discovery is being transformed by AI (Rikap and Lundvall, 2021). AI is becoming an extension of the human brain, likely resulting in an unimaginable increase in intellectual power. If AI is combined with the still-to-be-developed quantum computing, the result will be computing, problem-solving, and creative power many orders of magnitude higher than what the world now has. It will lead to the reorganisation of the mode of production (Kaplan, Gu and Sinha 2024), resulting in a new techno-economic paradigm, likely culminating in the end of wage labour as we know it. Of course, as with any other technology, there are both positive and negative aspects to this development of AI. Briefly, AI as autonomous weapons systems can increase the potential for devastating wars. Being able to programme itself and thus not restricted by objectives fed into its algorithms by humans, AI also poses a new threat of an extinction-level event to human beings (Hinton, 2024). Some manner of international agreements would be needed to set guardrails for the development of AI-based technologies.

However, the advent of this radically novel technology creates an opportunity for some country, some latecomer, to take the lead in its development. Simultaneously, there continue to be opportunities for the deployment of ICTs in new areas through short-cycle or second-generation technologies, as seen in the growth of e-commerce and social media by American and Chinese firms, and in India's development of hyper-scale identity and payments systems. But the critical technology in the current phase of global history is that of AI. Given its character as a general-purpose, dual-use technology, i.e., both civil and military, it has become central to geopolitical competition.

AI can be seen on its own or in combination with the still-nascent field of Quantum Computing, which can process many possibilities in parallel, unlike classical computers, which process one state after another. There are feedback links between the two technologies. Quantum computers need much less training to master a task, while AI is being used to help design quantum computation (Chou, Manyika and Neven 2025).

At the level of strategy, while the US has concentrated on developing quantum computing capabilities, China has concentrated on quantum communication technologies, which can make communication difficult to intercept (Krause, 2024). Together, such technological developments will shape the economy and military of tomorrow and are thus key areas of technological competition.

There are many forms of competition in the world across the spheres of economic, military, and diplomatic power, as well as soft power. But, as Cecilia Rikap and Bengt-Ake Lundvall put it: "… technology has become the central subject of geo-political conflict," (2021: 2). It is technology that will provide a strategic advantage over rival/s, just as West European militaries achieved a strategic advantage over their Asian rivals in the pre-colonial era through the military revolution (Parker, 1996). AI and quantum computing, with their ability to permeate all weapons' systems, may foster a new military revolution, providing a decisive advantage over countries with non-AI, non-quantum weapons' systems. "If access to quantum computers is limited to one or a few governments, it could upset the balance of power between different countries" (de Wolf, 2017).

In this competition, the latest assessment of AI by the Stanford Institute for Human-Centered AI (SHAI, 2026) concludes that there is little difference between the capabilities of US and Chinese AI models. "In March 2025, DeepSeek briefly matched the top US model, and as of March 2026, Anthropic's top model leads by just 2.7%" (SHAI, 2026: 4).

Though it is likely that the latest AI model might have helped the US pull a little bit ahead, it is still a close race. What needs to be noted are the different strategies and institutional conditions in which the technological competition is taking place.

US and Chinese Technology Strategies

In looking at US and Chinese strategies, we should note that competition between tech giants will promote the development of new technology, while catch-up would be better and more quickly achieved through centralised efforts. There is a high level of centralisation in China, with the Chinese state playing a big role in the allocation of funds and related support. But there is considerable competition in the Chinese economy, with provinces and even cities competing in funding and support. Nevertheless, it can be argued that competition among tech giants will promote the development of new technology, whereas catch-up would be better and more quickly achieved through centralised efforts. Since AI is a still-developing technology, the US would have an advantage over China in developing new models, particularly in the "race to AGI" or artificial general intelligence.

While the US has concentrated on AGI, China's AI developers are also racing ahead in AI applications, including embodied or physical AI, such as robotics, self-driving cars, and other autonomous hardware systems (Chan, 2026). Further, China has relied on open-source models to promote adoption of its technology. This will also help China in having its standards accepted in the Global South. It is in the deployment of embodied AI that US efforts are much more limited, though Tesla and Waymo have been developing self-driving cars.

There, however, is one factor that could hold back US progress even in developing AGI. The US, particularly in the age of IT, has depended heavily on attracting the best talent from around the world. That could be coming to an end, with the current US administration's anti-immigrant policies. The US has the most AI developers, far more than any other country. But the flow of these experts into the country is rapidly declining – it has dropped by 87% since 2017, and as much as 80% in 2025 alone (SHAI, 2026: 6).

Besides developing its own AI systems, the US has also tried to use export control to restrict the transfer of cutting-edge technologies to China. This extends from the most powerful Nvidia chips to Dutch photolithography machines used in chip manufacture. These export controls represent a technological chokepoint argument, a way of preserving the USA's first-mover advantage (Wilkinson, 2026).

US restrictions, however, have forced China to develop its own chips or reverse-engineer them. Reverse engineering is a time-honoured method employed by latecomers as they catch up. Of course, the US charges such steps as “stealing technology,” forgetting that it did the same in the 19th century (Vaidhyanathan, 2017). Wilkinson (2026) also notes that AI is largely about developing software, not just a matter of hardware. In developing cheaper AI models, Chinese companies are said to have used or distilled data from US models and combined less powerful chips to compensate for the unavailability of the latest cutting-edge chips. Whatever methods are used, China has certainly employed various software and hardware approaches to catch up with US model capacities.

Techno-nationalism and Imperialism

Although global networks and flows are important in the creation of knowledge, there is still a strong nationalist condition in its development. Nation-states play an important role in setting the R&D agenda or fostering links between different knowledge circuits. Firms operate in the context of national policies for higher or STEM education.

In the 19th century, attempts by the USA and Germany to catch up with Great Britain’s technology policies were pursued at the national level. Thus, government action in support of the high-tech industries of the time, or techno-nationalism (Ostry and Nelson, 1995: 61), is not new. The US state played a key role in the development of various technologies (Mazzucatto, 2013). Nation-states or civilisation-states also set technological standards that might be restricted to their boundaries. Or they take action against technologies from other countries, like China's action against Google, India's and the US's actions against TikTok, and the US's attempts to deny China access to advanced chips.

Thus, when late-comers try to catch up, there is an inevitable techno-nationalism in developing technologies and setting standards. Of course, there is also nationalism among technology leaders who try to prevent other countries from copying their advanced technologies (Chang 2000 and Nathan 2024). Techno-nationalism in the capitalist world, however, has also been the prelude to expansionism. This happens as successful techno-nationalist policies lead to the development of monopolies whose knowledge is protected by intellectual property rights, and these monopolies seek both to extend their markets and to secure high profits through external concessions, as nation-states also try to expand their spheres of influence. This expansionism of monopoly capital allied with national states was analysed by Hobson, Lenin and Luxemburg as the basis of imperialism and the concomitant inter-country struggle over spheres of influence. Later analyses by Giovanni Arrighi (1994) and Ho-fung Hung (2022) separately treat these two factors: market expansion by monopoly capital and the state's creation of colonies or spheres of influence.

Ugo Pagano (1995)[6] brought in additional factors to account for competition between nation-states as imperialism. These are symbolic utility a la Robert Nozick, 'the utility that we get from what we think we are' (Pagano1995: 17); and positional goods, in Hirsch's analysis (1977), the exercise of power and domination which necessarily means power and domination over someone or some nation. The attempt to acquire positional goods leads to competition between powers. As Pagano points out, " 'Positional competition' is much harder and sometimes more violent, than competition for 'private' goods," [such as wealth] (Pagano, 1995: 21). This positional competition is seen in the geo-political rivalry to establish or re-establish global dominance.

In contradiction to the analysis of imperialism as a necessary concomitant of monopoly capitalism and national competition, Schumpeter thought that national competition could be overcome by the desire to accumulate (1919). Keynes too felt that dangerous tendencies could be channelled into the accumulation of wealth. But as Pagano sums it up, "Individuals may wish to define themselves as members of powerful nations and may wish to consume pride and superiority with respect to other national and ethnic groups. Unfortunately, if many national groups share these wishes, an overinvestment in nationalism results. This over-investment by possibly rational agents may perhaps help to explain some of the most regrettable aspects of our age" (Pagano, 1995: 27). These additional factors brought into the analysis by Pagano extend the motivations for imperialism beyond monopoly capital to the nation-state and even to the individuals comprising a nation. They also extend inter-national competition beyond nations with monopoly capitalism.

Nationalism, leading to wars between nations, exists even in relatively small nations, as we can witness in the recent Thai-Cambodian military clashes. But intellectual monopoly capitalism certainly fuels notions of great-power recognition, seen in the popularity of slogans such as Trump's 'Make America Great Again,' which can be understood as an effort to re-establish pre-eminence in the world order. Simultaneously, it is also an attempt to redefine the US as a 'white Christian nation' (Du Graz, 2024). As both China and India seek to define themselves as civilisation-states rather than mere nation-states, notions of greatness are intertwined with ideas of domination, whether over the world or over regions identified as civilizational spaces. Civilizations are defined by central worldviews, whether of Confucianism in China or Hinduism in India; all other worldviews within the civilizational space, whether of Buddhism or Islam, have secondary status. Clash of civilizations (Huntington, 1996) with a vengeance?

We now look at what contemporary technological competition has meant to the world order. This is the impact of knowledge as an input into geoeconomics and geopolitics.

[6] This portion owes much to Ugo Pagano (1995).

While we stress the role of technological competition in geoeconomics, we do not claim that it is the only factor in geopolitics.

Current Technological Competition and Bipolarity

There is much discussion on the world economy being multipolar.[7] While the fall of the Berlin Wall ushered in a unipolar world of the US, that hegemony has clearly declined over the last decade or so. The rise of China is the key factor in ending US unipolarity. But, is there, along with the rise of China, also a rise of other poles, such as the other BRICS countries, in the world economy? In discussions in India, including in official discourse, it is almost taken for granted that the world is multipolar and, in a form of wishful thinking, that India is one of those poles.

Can there be a way to measure polarity to answer the question: Is the world multipolar or bipolar? In this empirical analysis, we make two assumptions: (1) economic capability is the base of hard power, including military power, and leads to soft power with a lag; and (2) economic capability is based on, though broader than, leadership in the general-purpose technology of the era.

A subsidiary assumption is that the economy of production of goods and services (the so-called real economy) is the base of finance, even of financialisation in the world economy.[8] For instance, it is the global offshoring of production that has resulted in the extreme financialisation of US capital, which no longer requires investing much of its revenue in production and instead leaves it with enormous profits invested in financial assets, including through stock buybacks.

As will be seen below, despite our assumption of the greater importance of the real economy, we have included two financial indicators: foreign direct investment (FDI) and stock market capitalisation. We have not, however, attempted to include an indicator for the privilege and power of the US dollar as the world's reserve currency. At the base of polarity in the world economy lies the domination of the era's general-purpose technology, whether in Pax Britannica or Pax Americana.

We identify a central hub, or pole, of the world economy through economic capabilities and roles across several critical factors. Below (Table 2) we list the main economic capabilities considered, along with the indicators used in the statistical analysis.

[7] The analysis and measurement of polarity is taken from Nathan and Rahul (2026).

[8] I am grateful to an anonymous external reader of The India Forum for pointing out that the calculations have been based on an assumption that finance matters less than the real economy.

Table 2: Dimensions and Indicators to Measure Polarity

Markets (Goods and Services)	Gross Domestic Product (GDP) Exports of goods and services Manufacturing value added
Advanced Technologies	High-tech manufacturing exports Information and Communication Technology (ICT) service exports Industrial robots Artificial Intelligence (AI) ranking
Headquarter Firms	Firms in Forbes 2,000 Brands in Top 2,000
Critical Raw Materials	Balance of trade, crude oil Rare earths production
Finance	FDI outflow Stock market capitalisation
Knowledge	Patents granted (Patent Cooperation Treaty; PCT) R&D expenditure (Purchasing Power Parity; PPP) Companies in top 2,000 in business enterprise R&D (BERD) AI publications Universities in Top 250 as per QS Rankings

Source: Author's creation.

Countries Selected

The analysis naturally began with the US and China for polarity calculations. The other BRICS countries—Brazil, Russia, India, and South Africa, often grouped together as the major emerging economies—were included, as were Germany, Japan, the UK, and South Korea, all important centres of technology development. Saudi Arabia and the United Arab Emirates (UAE) were added for their role as exporters of crude oil and, reportedly, as emerging centres for technology development. Turkey was included as another emerging economy.

Index

The methodology of calculating the Polarity Index is given in the detailed paper.[9] The results are given below.

When we define global economic hubs as peaks, Figure 2 shows that there are just two peaks in the world economy, the USA and China.

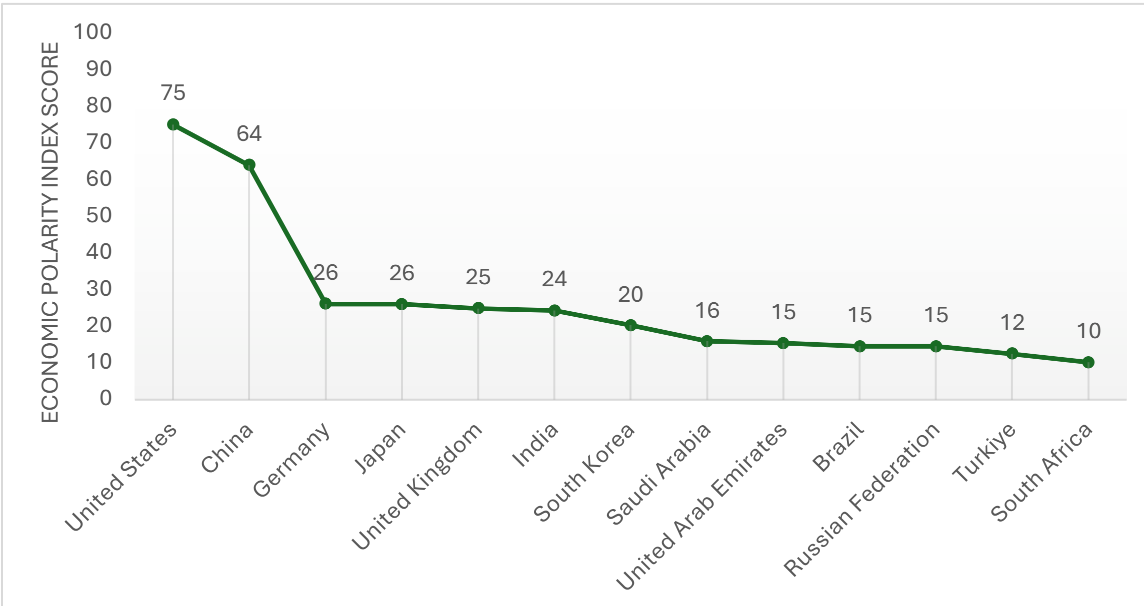

Figure 2: Peaks in the World Economy

The world is certainly not unipolar—the relatively narrow gap of 11 points between the USA (75) and China (64) shows this. But is it bipolar or multipolar? Multipolarity in the world economy can be defined as a situation of "relatively equal distribution of capabilities… with three or more consequential powers" (Posen 2009: 350). Table 2 shows a large difference between the economic capabilities of the first two and the next-ranked powers: Germany, Japan, the UK, India, and South Korea. There is no relatively equal distribution of economic capabilities between the USA and China, on the one hand, and the next-ranked powers, on the other, leading to the conclusion that the world economy is bipolar.

What stands out is the difference between the first two countries—the USA and China—and the rest. Even if the differences among the other countries seem relatively minor, the gap between the two poles and the rest is stark and would not change in any calculation of economic capabilities in the contemporary world economy. A sensitivity analysis confirmed this: the positions of the big two did not change, and the relative positions of

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[9] Available on request from the author.

the other powers remained largely stable. These results show that our index is quite robust.

Figure 2, with its two peaks and steep fall into a plateau, follows a power-law distribution (Barabasi and Albert 1999), where few countries (two) have high values and many (11) have relatively low values; or “winners-take-most”.

Why is there such a power law distribution of economic capabilities in the world economy? Being at the knowledge frontier in propositional knowledge can translate into being at the production frontier. The main conditions for this movement are links between universities and research centres as knowledge creators and corporations as producers, combined with macro- and micro-level strategies for being technological leaders. Below are some examples of how China achieved its strategy of being a technology leader.

In the case of solar electricity generation and electric vehicles, the initial patents in solar panels and electric vehicles were initially from Germany and Japan, but then mainly from China (UNCTAD 2023). Over time, China has emerged as the dominant player in the production of both solar panels and electric vehicles.

In the electronics sector, the Chinese state-owned electronics research unit was handed over to Huawei (Fan 208), enabling it to link production-cum-marketing issues to research priorities. The importance of such links between different knowledge circuits has become apparent as Huawei works to catch up with the US frontier in chip design and production. Leadership in knowledge and technology creation drives economic polarity through multiplicative and feedback effects—with the result that the US or China leads or comes second in most indicators, producing the winner-takes-most phenomenon.

How is this bipolar technological competition likely to develop?

Constraints in Technological Development

While state guidance on the direction of knowledge development and innovation has helped make China the dominant force in renewable technologies and electric vehicles, the weaknesses of state doctrines in handling novel situations requiring innovative solutions were evident in China’s initial responses to COVID-19. “Tragically, local authorities in Wuhan were slow to raise concerns about a scary new SARS-like virus in the early days of COVID-19. The fear factor of the corruption drive helps to explain the delayed response” (Bell 2022: 81; also see Huang 2023).

Such restrictions affect not only the particular discipline involved but also other disciplines, as there are network effects connecting various knowledge domains. The borrowing of theory across disciplines also brings up the importance of decentralized networks, with various theories and doctrines competing.

Centralisation can help achieve a clear goal, as in the catch-up process. But in developing novel technologies, such as AI or quantum computing, there is a role for decentralized, competing networks. As Qian and Xu (1993) point out, such centralisation does not allow for parallel research and could be understood as an important factor in the Soviet Union falling behind the USA, despite not spending less on R&D.

The central state will necessarily have a role in technological strategy, as in deciding on priority sectors. A market-driven strategy would, for instance, not pay enough to develop climate-friendly technologies. But the state or religious doctrines should not have a role in deciding what may or may not be investigated, and what conclusions may or may not be drawn. This holds even for religious and nationalist doctrines or sensibilities.

Such restrictions, however, are not confined to China. Under Trump, the USA is trying very hard to ban areas of enquiry, such as critical race theory and gender theory, and is also withdrawing federal funding for environmental research and, more generally, attacking academic freedom (Appadurai and Pollock 2025). But, in contrast to the attempt to impose a singular doctrine in China, one should note the considerable contestation over doctrines in the US. All of this should make one wary of linear predictions, extrapolating from the present trends and forecasting the inevitability of an Asian or Chinese 21st Century. Non-linearity in knowledge creation is particularly important for novel technologies, such as AI and quantum computing.

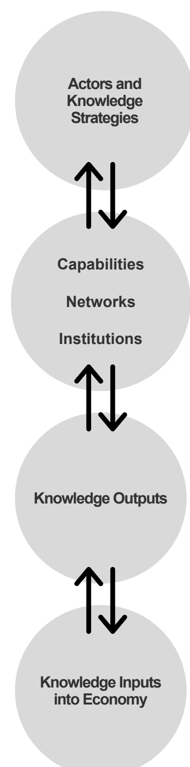
7: Synthesis - and A Way Forward

We end this Element with, first, a synthesis of the analysis presented so far, and, then, a short note on a possible way forward to realize the goal of reducing global inequality.

Synthesis

The rationale for this Element is the need to formulate strategy on knowledge as an output of the economy, not just as an input. As an output, knowledge is framed by strategy and resulting policy, whether explicit or implicit, of actors in the knowledge economy.

Fig. 3 The Knowledge Ecosystem



Actors and Knowledge Policy

In the first circle (Fig. 3), are the actors including the state and its agencies, organisations, whether firms, educational and research organisations, individuals, groups such as epistemic communities; not just users and consumers of knowledge but also producers, such as usually ignored actors, such workers, women, indigenous peoples, and others either directly or through knowledge embodied in technology. Now AI agents are also partners, and thus actors in the knowledge economy.

Knowledge strategy of any or all the above agents works to produce knowledge outputs through the following factors: capabilities of the actors, networks connecting them, and institutions, or rules of access and performance for the actors.

Capabilities

The capabilities of actors are not only in the absorption of knowledge but also in its creation at all levels, whether in firms, customers, or users, not just in learning but also in knowledge creation. Those considered consumers not only learn to use the technology but also develop knowledge about, for instance, its usability or its need for adjustment.

An important capability is the ability to learn to learn. This becomes even more important when AI can carry out many technical tasks. Firms, too, become learning organisations; learning by doing as well as acquiring implicit knowledge by investment in R&D. Firms, however, require strategic capabilities to acquire knowledge, change production models, and introduce innovations. Workforce development is part of firm-level capability building.

Actors may build different capabilities and specialisations based on the division of labour, which is also a division of knowledge. However, it is the division of knowledge or labour that creates different capabilities, which means that policy can change the existing division of labour by actors, including countries, acquiring different sets of knowledge, a task that is made cheaper and faster by the spread of AI.

Networks

Networks are the structural relations between different actors in the knowledge economy. Knowledge is created by individuals or groups, but they all act within networks. Now we act with AI agents as partners in networks, but there are other non-human partners too, leading to an epistemology of inter-species relations in knowledge creation. However, it is also necessary to break down phenomena into their constituent parts and analyse them separately before reconstituting an analysis of the whole. This reconstitution of the whole, which requires analysing large data sets, is a particular area where AI's capabilities can make a difference.

Network connections, more than ever before, span the whole world. They not only transmit knowledge but also serve as a source of new ideas, helping to spread ideas across domains. Thus, knowledge networks benefit from both dense and sparse, or strong and weak, connections, the former in developing a domain and the latter in crossdomain advances. Policy interventions are needed to fill in structural holes in connections between domains, as between conceptual knowledge (knowing that) and procedural knowledge (knowing how to). Diversity in networks brings in different experiences and standpoints.

Institutions

By institutions, economists usually mean the rules of access to resources. But we extend the meaning of institutions to include the operational rules of epistemic communities, systems that influence, promote or even constrain the search for knowledge.

Knowledge systems are subject to rules of enquiry. They may be relatively closed to ideas from outside their cultural contexts, or they may be open to such ideas from other cultures and disciplines. Along with this, there can be policies or rules, often set by states or religio-cultural organisations, that limit what can and cannot be investigated. Epistemic communities also enforce such restrictions through peer review. It would be interesting to count the number of Nobel prize-winning analyses that have, initially and perhaps for a long time, been rejected by their epistemic communities.

Incentives, ranging from honours to monetary incentives, play a role in the creation of knowledge and its manifestations as technology. Competition in the market and competition to secure markets are historically powerful drivers of knowledge creation; while protected markets retard knowledge-seeking by firms.

Mainstream economic analysis favours incentives such as monopolies built on exclusive intellectual property rights. However, intellectual property rights also act as exclusionary devices. Acknowledging the public-good character of knowledge, whose use is non-rivalrous or non-subtractable, may yield other systems with lower incentives, such as compulsory licensing, which may make the use of knowledge and technology more open, not create the “winners-takes-most” outcome, and thus reduces international inequality.

Competition and cooperation are both part of rules of functioning in international knowledge systems and economic relations. National strategies may be framed with competition as the overriding imperative. However, national strategies based on continued interaction among nations, rather than a one-time, Prisoners’ Dilemma-type engagement, may offer competitive methods that do not preclude cooperation.

The creation of knowledge outputs, however, is not the end of the story, nor of the need for feedback loops. Knowledge must be turned into technology, and that technology introduced as inputs into production and as knowledge in economic and social organization. At each step, feedback is needed to improve understanding of the processes being addressed, not only from knowledge outputs to production, but also from production back to knowledge systems. To reiterate, feedback loops are critical to realising non-linearity in the domain of knowledge and realising increasing returns in the economy.

Knowledge Eco-system

What do the system of actors, their capabilities, networks and institutions constitute? So far, we have used the term the knowledge economy. We might stretch this to the knowledge ecosystem, since we include not only economic matters such as capabilities and incentives but also the rules governing the functioning of epistemic communities. The latter cannot be reduced to economics. Consequently, the knowledge ecosystem might be a more appropriate term for the whole knowledge system.

Further, the constituent parts, actors, their capabilities, the networks and institutions within which they function do not simply add up to the whole ecosystem. There are interactions and, importantly, feedback loops between the parts, within and between circles in our figure. For instance, the rules governing epistemic communities would influence how networks operate, while the buildup of capabilities would also change network functioning, as better-performing nodes attract more connections. These feedback loops are important in creating non-linearities or increasing returns in the knowledge ecosystem, where nodes that perform better might multiply their advantages across domains rather than just within them. The "to him who hath, more shall be given" (as in the Bible according to Matthew) character of knowledge networks is, we might say, of a whole that is more than its parts, a feature of knowledge ecosystems.

Feedback loops, however, are not an invariant feature of knowledge ecosystems; which is why the figure has arrows in both directions. Experience that negates theoretical propositions may not go back to those formulating theory. There could be a one-way, linear relation, which would then lead to a weak knowledge ecosystem. Policy is needed to establish or ensure two-way, non-linear relations between spheres. Effectively establishing two-way relations between spheres, or filling structural holes, is then a necessary condition for emerging as an important player in international knowledge competition.

A Way Forward: From Monopoly to Commons

Reducing global inequality requires low- and middle-income countries in the Global South to develop their knowledge economies and increase per capita productivity by strengthening technological capabilities. We also saw that they can overcome the middle-income trap by shifting from using knowledge to creating it. Successful knowledge creators, however, also usually seek to protect their knowledge through intellectual property rights and even form monopolies. Knowledge creation in frontier technologies, or of the new general-purpose technology, becomes the basis for geopolitical, even great-power, competition.

While technological development would increase per capita income, there could still be a high level of inter-country inequality in the global economy. At present, with the monopolisation of frontier AI technology, there could be an increase in global inequality driven by the dominance of tech giants headquartered in a couple of countries, the USA and China (UNDP, 2025). There are moves to develop what is called AI sovereignty, i.e., a condition in which a country controls its technology stack, including infrastructure, data, and AI models. But when the manufacture of high-end chips and the creation of AI models are both with a handful of companies, with their knowledge protected by the current intellectual property rights (IPR) system, it is difficult to actually envisage AI sovereignty of countries whose companies do not own either chip knowledge and manufacture or the AI companies making the LLMs. This is both a matter of IPRs and of the secrecy of source codes. We could end up in a world order dominated by the competition between technological giants.

The national control over content is very limited when it is restricted to localization of data and location of data centres and AI systems. It is the technology behind them that is key to national control. Of course, the notion of AI sovereignty has been put forward by middle powers, such as European countries and India.

Is there a way of reducing dependence on the tech giants and their headquarter countries? To formulate a knowledge strategy to address dependence and inequality in the world economy, it is necessary to return to the fundamentals of knowledge as an economic good.

Knowledge is a public resource in that its consumption or use is non-rivalrous (Romer, 1995) or non-subtractable (Hess and Ostrom, 2013). However, the management of knowledge in the capitalist economy has turned it into a resource whose use is excludable, i.e. its use can be restricted by the laws, both national and international, in place. The laws of intellectual property rights (IPRs) restrict its use and create a legal monopoly. The creation of such a monopoly is justified as a necessary incentive.

What is an adequate incentive for knowledge creation? Schumpeter held that the creation of monopoly was the incentive for knowledge creation that results in innovation. This, however, has the negative effect of hindering the economic advancement of the rest of the world by preventing them from using and developing the most advanced knowledge available.

As discussed in detail by Nathan (2024), such monopolisation of knowledge has underpinned global inequality since 1800, from the colonial period of capitalism onwards. At present, with tech companies now owning AI, there is a danger that global inequality will reach an unprecedented level and that the struggle for global dominance between two economies or tech giants will even threaten human existence. Of course, this is not the first time human existence has been threatened by great-power competition. But we certainly need to find ways of existing that do not continuously keep us on the brink of disaster.

Sen (2004) points to the need for incentives in knowledge production, while Arrow (1994) refers to knowledge as a social product and not that of an individual. This social nature of knowledge production can be extended to that undertaken by corporations. It has been noted that much knowledge is generated within networks; in fact, one might say that all knowledge is created within networks, and that these networks span the globe.

Further, as Mazzucato (1993) argued, the creation and commercialisation of knowledge involves both public and private corporations. In the development of AI, the Stanford University Human Centered Intelligence (2025), lists the open science involved in the development of AI:

- The back-propagation algorithm, first shared openly in the 1980s, enabled deep learning's revival.
- Successful deep learning techniques were then pioneered at universities, particularly for speech and image recognition in Geoff Hinton's lab at the University of Toronto.
- Open datasets like TIMIT, TREC, NMNIST, Imagenet and Stanford Alpaca provided reproducible benchmarks and common ground for AI progress.
- Opens-source code/libraries such as the Stanford CoreNLP toolkit and later TensorFlow, PyTorch and FlashAttention offered free access to cutting edge technologies.
- Shared benchmarks and challenges (e.g. CLUE, ImageNet competitions) trained generations of AI researchers and engineers.

All of this points to the importance of public science, and public data, which the corporations, whether OpenAI, Anthropic, Alphabet, META or Microsoft, are turning into private, proprietary products. As SHCI put it, what we need is team science and that too across continents. "We have a fleeting opportunity to shape the trajectory of AI before it shapes us," Etchemendy, Landay, Li and Manning (2025: 6).

However, even if universities were to champion open science, that still leaves open the question: what should one do about the system of intellectual monopoly capitalism? And what should be the incentive structure for corporate knowledge creation? As discussed in Kingston (2001), there can be a system of compulsory licensing of patents, which would not create a monopoly. Fees would be based on an estimate of R&D costs, with a return of, say, 10%, plus an additional percentage for risk. The important point is to provide incentives that do not create monopolies. Right now, monopolisation is the incentive.

There is a need to combine development objectives, particularly for low- and lower-middle-income countries, which will reduce inter-country inequality, itself a global public good (Kaul et al. 1999), with the provision of global public goods, such as knowledge (Stiglitz 1999), improved public health, and climate. The adoption of policies, however, requires a change in how we understand and deal with cooperation and competition.

There is a tension between competition and cooperation even in general evolutionary theory, existing right from Darwin, who "narrowly taken, underestimated collaboration" (Kaufmann, 2016: 258). There is both cooperation and competition in society and in nature.

Even in nature, rather than the idea that competition for sunlight and other nutrients is all there is to the relation between trees, "There is now a substantial body of scientific evidence that refutes that idea. It shows instead that trees of the same species are communal, and will often form alliances with trees of other species. Forest trees have evolved to live in cooperative, interdependent relationships, maintained by communication and a collective intelligence similar to an insect colony. These soaring columns of living wood draw the eye upward to their outspreading crowns, but the real action is taking place underground, just a few inches below our feet" (Grant 2018), the underground mycorrhizal networks created by fungi.

There is also a moral dimension to the different ontologies we might adopt. In animism and posthumanism, no being, human or non-human, has a value of zero. All beings then have moral standing and rights. This extension of moral standing from humans to non-humans is reflected in New Zealand law, which now grants rights to rivers, and in the recent decision by North American indigenous peoples to declare the Colorado River a being with rights. But in the Cartesian ontology, there is no value to non-human nature. Thus, there is a need to move beyond Cartesian ontology to a multi-species, relational ontology including AI agents as part of the posthumanist ontology.

Economic analysis, at least since Malthus, tends to see competition as the key relationship among individuals, classes or social groups, and nations. But, without cooperation, even through the division of labour, whether in the household, factory, society or the world, we are simply incomplete, as the African philosophy of *Ubuntu* states and animist or posthumanist relational ontology states, and not just less efficient. In the current global scenario, however, competition and conflict dominate the world, with extinction-level threats to the human species itself.

Thus, there is a need to move beyond the framework of self-interest, even enlightened self-interest, as in Adam Smith, and the efficient allocation of scarce resources, as in Lionel Robbins, that have dominated economic analysis. We could start with the inclusive fitness theory in evolutionary biology formulated by Hamilton (1964): that a trait - such as cooperation - will undergo positive change due to natural selection if and only if $rb - c > 0$, where r is relatedness, b benefit and c cost (Birch, 2017; Bowles and Gintis, 2001). b can be the welfare benefit of climate-friendly or global health benefits from mitigating global pandemics, or the supply of various global public goods. The benefits to more related peoples, r, (e.g. those within a claimed civilizational or national identity) could be rated higher than the same benefits to more distant peoples. Such an approach would be an advance over the simple self-interest and Prisoner's Dilemma basis of current economic analysis. It would be amenable to quantification of the net welfare of global public goods, thereby promoting discussion of their costs and benefits.

Changing the international intellectual property regime to make critical technological knowledge available either in the commons or on a compulsory licensing basis (with sufficient incentive payments to cover costs of production and risks) would promote both development of low- and lower-middle income countries, and the provision of other global public goods related to public health and the climate. The elimination of global monopoly and accompanying monopsony power would reduce, if not eliminate, the extraction of high profits from developing economies.

Making critical technological knowledge open access, including through compulsory licensing, would increase the cooperative element and reduce the competitive element in the world economic order. Further, by strengthening the cooperative element in international economic relations, cooperation could emerge as a norm and even affect other areas of international relations. Cooperation in international economic relations could begin by developing a climate-friendly system and agreeing on guardrails for AI and other technologies that could pose risks of human extinction.

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